

**IN THE UNITED STATES DISTRICT COURT
FOR THE WESTERN DISTRICT OF TEXAS
WACO DIVISION**

DALI WIRELESS, INC., a Delaware Corporation,

Plaintiff,

V.

CORNING, INC., a New York Corporation,
and CORNING OPTICAL
COMMUNICATIONS LLC, a North Carolina
Limited Liability Company,

Defendants.

Case No. _____

JURY TRIAL DEMANDED

COMPLAINT

Plaintiff Dali Wireless Corporation (“Dali”) files this Complaint against Defendants Corning, Inc., and Corning Optical Communications LLC (collectively “Corning”).

NATURE OF THE CASE

1. This is a case of infringement of two patents: (1) U.S. Patent No. 9,826,508 (the “508 patent”), and (2) U.S. Patent No. 9,769,766 (the “766 patent”), collectively referred to as “the Patents-in-Suit.”

2. Defendant Corning has been making, selling, using and offering for sale, DAS systems such as Optical Network Evolution (“ONE”) products and the SpiderCloud Enterprise Radio Access Network (“E-RAN”) System that infringe the ’508 and ’766 patents in violation of 35 U.S.C. § 271. Dali seeks appropriate damages to compensate for Corning’s infringement.

THE PARTIES

3. Dali is a Delaware corporation having its center of operations in Burnaby, British Columbia, Canada, where all its technical and financial employees, documents, engineering, and

product development are based. It also has an address in Menlo Park, California for forwarding of domestic mail and telephone calls to its center of operations.

4. Founded in 2006, Dali began as a designer and manufacturer of power amplifiers used in radio frequency (“RF”) communications. Dali is known within the industry as an innovator in providing end-to-end, software defined digital radio distribution solutions that can be implemented in Distributed Antenna Systems (“DAS”) used for cellular, public safety, and other RF communications. Dali is a world-wide innovator in digital radio distribution systems and digital predistortion technology that revolutionized in-building and outdoor wireless coverage and capacity. Dali’s groundbreaking products have been consistently recognized by industry publications. For example, Dali has been recognized as a “Hot Tech Innovator” by ABI Research and was ranked No. 1 in innovation in the latest ABI Research report, “In-Building Wireless, DAS Vendor Competitive Assessment.” Dali’s systems improve upon traditional DAS by allowing the dynamic allocation of wireless coverage and capacity.

5. Corning, Inc. is a New York Corporation with offices at 8201 North FM 620, Austin, Texas, 78726. Corning, Inc. is registered to conduct business in the state of Texas and has appointed the Corporation Service Company, located at 211 E. 7th St., Suite 620, Austin, Texas 78701, as its agent for service of process.

6. Corning Optical Communications LLC, is a North Carolina Limited Liability Company. On information and belief, Corning Optical Communications LLC is a wholly owned subsidiary of Corning, Inc.

7. In 2017, Corning acquired SpiderCloud Wireless, a company that developed the SpiderCloud E-RAN system. On information and belief, SpiderCloud Wireless was merged into Corning Optical Communications LLC.

8. On information and belief, Corning, Inc.'s operations in Austin, Texas are substantial and varied. For example, a search on LinkedIn.com for "Corning, Inc. Austin, Texas" returned 504 results. Corning, Inc. employees in Austin, Texas, list varied job titles such as "Sr. Litigation Counsel – Director eDiscovery, Privacy, and Cyber Security at Corning Incorporated," "eDiscovery Advisor at Corning Incorporated," "Marketing Manager at Corning Incorporated," "Global Product Line Manager," and many others.¹

9. A significant part of Corning's operations in Austin, Texas, involves networking and communications. In 2017, Corning Inc. announced the acquisition of virtually all of 3M's Communication Markets Division that was headquartered in Austin, Texas.² The acquired division is in the business of providing optical fiber and copper passive connectivity solutions for the telecommunications industry and structured cabling solutions for telecommunications system integration services; the business had annual global sales of approximately \$400 million.³

10. A search on LinkedIn.com confirms that Corning's business operations in Austin, Texas involve networking and communication. Corning Optical Communications employees in Austin, Texas, list varied job titles such as "Mold Build Project Manager," "Federal Account Manager," "Sales Engineer," and "Market Development Director – In Building Solutions" among

¹ See https://www.linkedin.com/search/results/all/?keywords=corning%2C%20inc.%20Austin%20texas&origin=GLOBAL_SEARCH_HEADER, last accessed on September 8, 2020.

² See <https://www.corning.com/worldwide/en/about-us/news-events/news-releases/2017/12/corning-to-acquire-substantially-all-of-3ms-communication-markets-division.html>, last accessed on August 10, 2020.

³ See <https://investors.3m.com/news/news-details/2017/3M-to-Sell-Substantially-All-of-Its-Communication-Markets-Division/default.aspx>, last accessed on August 10, 2020.

others.⁴

11. On information and belief, Corning operates at least two additional campuses in Texas, one in McAllen, Texas in the Southern District, and another in Keller, Texas in the Northern District.

12. By registering to conduct business in Texas and by maintaining facilities in Austin Texas, Corning has a permanent and continuous presence in the state of Texas and a regular and established place of business in the Western District of Texas.

JURISDICTION AND VENUE

13. This is an action for patent infringement arising under the Patent Laws of the United States, Title 35 of the United States Code.

14. This Court has original subject matter jurisdiction under 28 U.S.C. §§ 1331 and 1338(a).

15. This Court has personal jurisdiction over Corning because Corning has a place of business and regularly transacts business in this District.

16. Corning has committed and continues to commit, acts of infringement of Dali's Patents-in-Suit in violation of the United States Patent Laws, and has made, used, sold, offered for sale, marketed and/or imported infringing products into this District. Corning's infringement has caused substantial injury to Dali, including within this District.

17. Venue is proper in this District pursuant to 28 U.S.C. §§ 1400 and 1391 because Corning maintains a regular and established place of business in this judicial district and has

⁴ See https://www.linkedin.com/search/results/all/?keywords=corning%20optical%20communications%20austin&origin=GLOBAL_SEARCH_HEADER, last accessed on September 8, 2020.

committed acts of infringement in this district.

THE PATENTS-IN-SUIT

18. The '508 patent is titled "Neutral Host Architecture for a Distributed Antenna System" and was issued by the United States Patent Office to Paul Lemson, Shawn Stapleton, and Sasa Trajkovic on November 21, 2017. A true and correct copy of the '508 patent is attached as Exhibit A.

19. Dali is the owner of all right, title and interest in and to the '508 patent with the full and exclusive right to bring suit to enforce the '508 patent.

20. The '508 patent is valid and enforceable under the United States Patent Laws.

21. The '766 patent is titled "Self-Optimizing Distributed Antenna System Using Soft Frequency Reuse" and was issued by the United States Patent Office to Seyed Hejazi and Shawn Stapleton on December 10, 2018. A true and correct copy of the '766 patent is attached as Exhibit B.

22. Dali is the owner of all right, title and interest in and to the '766 patent with the full and exclusive right to bring suit to enforce the '766 patent.

23. The '766 patent is valid and enforceable under the United States Patent Laws.

FACTS COMMON TO ALL CLAIMS

24. From 2010 through 2014, under the terms of a non-disclosure agreement Corning extracted Dali's proprietary and patented technology know-how through a series of conferences and meetings through which Corning became well-informed of Dali's portfolio. For example, in 2011 Dali presented its proprietary technology to Corning, including information from various patent families. This presentation included Dali describing how its portfolio would block other competitors from entering the market without licensing its patents. Subsequently, Corning's IP

counsel conducted an extensive review of Dali's patent portfolio and Corning provided feedback on the portfolio to Dali. In response to the presentation, Corning requested further detail on Dali's technology:

From: Cune, William P. [REDACTED]@corning.com]
Sent: Friday, March 18, 2011 10:08 AM
To: Lee, Albert
Cc: Lemson, Paul
Subject: RE: Meeting invitation: Dali Wireless - Corning DAS

Albert,

As discussed at the end of the call...

Thank you for the Dali management teams time today. We are very interested in learning more and investigating potential technology and product synergies. I'd like to push the technology discussion as far as we can to have our team really understand the capabilities and limits (there are always tradeoffs) and so they can properly advise our leadership on the core capabilities and benefits of collaboration. I'd also like to understand your commercial value proposition relative to the DAS, RRH, Picocell, enterprise femtocell, ALu Cube, etc. competition (product cost savings, turnkey cost savings, BTS cost savings, future proofing, upgradeability, etc.). I look forward to further discussions, if we agree to go that far.

I would also like to understand more about your current VC round, your funding history, and perhaps hear your investor pitch. This is not my area and I would need to involve our Strategy team but I think it is worth the discussion. Would you be interested in having these discussions with Corning and what is the timing?

Thank you,

Bill

Bill Cune

Program Director - IDAS
[REDACTED] wireless
[REDACTED] wired
[REDACTED]@corning.com

25. In May 2012, Corning and Dali began weekly teleconferences between Corning's product line management team and Dali's technical personnel. From May through July of 2012, Corning's IP counsel conducted in-depth IP due diligence on Dali. Throughout the remainder of 2012 and 2013, Dali and Corning worked on various technical projects aimed at jointly providing DAS systems to AT&T.

26. On June 3, 2014, Corning's Corporate Development team met with Dali to discuss a potential acquisition. At the meeting, Dali again provided a detailed discussion of Dali's patented inventions. On July 5, 2014, Corning conducted extensive acquisition diligence at Dali's facility in Burnaby, Canada, diligence that included studying Dali's patents.

27. Through Corning's various diligence projects and conferences with Dali, Corning

became well aware of the nature and scope of Dali's extensive patent portfolio. Despite having actual knowledge of Dali's patents, Corning made no efforts to ensure that its current and future products did not infringe Dali's many patents. Corning proceeded to incorporate Dali's patented technology into its own products despite such knowledge.

FIRST CAUSE OF ACTION
(PATENT INFRINGEMENT UNDER 35 U.S.C. § 271 of '508 PATENT)

28. Dali re-alleges and incorporates by reference all of the foregoing paragraphs.

29. On information and belief, Corning has infringed and continues to infringe, either literally or under the doctrine of equivalents, one or more claims, including at least claim 1, of the '508 patent in violation of 35 U.S.C. §§ 271 et seq., directly and/or indirectly, by making, using, importing, selling, and/or offering for sale certain equipment and systems relating to Corning's ONE Wireless Platform, such as ONE's currently advertised Mid-Power Remote Unit or "MRU". *See, <https://www.corning.com/media/worldwide/coc/documents/applications/wireless/wireless-specs/CMA-422-AEN.pdf>* (last visited on July 21, 2020).

30. On information and belief, Corning has been and currently is infringing the '508 patent by the manufacture, use, sale, offer to sell and/or importation of its products including at least the ONE MRUs under 35 U.S.C. § 271.

31. Claim 1 of the '508 patent recites the following:

[preamble] A remotely reconfigurable remote radio head unit for transporting radio frequency signals, the remotely reconfigurable remote radio head unit comprising:

[A] at least one remotely reconfigurable access module adapted to receive reconfiguration parameters from a remote location,

[B] a plurality of band modules, each of the plurality of band modules having separately reconfigurable parameters in response to the reconfiguration parameters received from the at least one remotely reconfigurable access module, each of the plurality of band

modules supporting one of a plurality of frequency bands of the radio frequency signals being transported, and

[C] an interface adapted to provide:

[C1] electrical and mechanical connection for mounting of the plurality of band modules; and

[C2] bidirectional digital communication between the at least one remotely reconfigurable access module and each of the plurality of band modules.

32. On information and belief, and based on publicly available information, at least Corning's ONE MRU satisfies each and every limitation of at least claim 1 of the '508 patent.

33. Regarding the preamble of claim 1, to the extent the preamble is determined to be limiting, Corning's ONE MRU provides the features described in the preamble. The preamble recites, "[a] remotely reconfigurable remote radio head unit for transporting radio frequency signals, the remotely reconfigurable remote radio head unit" Corning's ONE MRU is described in its user manual as a remote radio for transporting radio frequency signals. For example:

The MRU is a mid-power (2 W) remote solution for the Corning ONE™ Wireless Platform system. The MRU provides remote indoor and outdoor coverage. It is a fiber-fed, compact and scalable multi-service solution designed to complement the Corning ONE Wireless platform by providing complete RF open space coverage for large-scale public venues such as campus applications.

Corning Mid-Power Remote Unit (MRU) User Manual, Exhibit C at 9. See also MRU Brouchure at <https://www.corning.com/catalog/coc/documents/brochures/CMA-434-AEN.pdf> (last visited on July 21, 2020). Additionally, Corning's documentation explains that the MRU is remotely reconfigurable from the Headend Control Module. For example:

Management and configuration options are provided for each MRU service via a Web session to the headend control module (HCM). The HCM enables centralized, single-source local and remote management of all system elements.

Exhibit C at 6. Thus, to the extent the preamble of claim 1 is limiting, Corning's ONE MRU meets it.

34. The Corning ONE MRU also meets all the requirements of limitation A of claim 1. Limitation A requires "at least one remotely reconfigurable access module adapted to receive reconfiguration parameters from a remote location." According to the MRU manual, the MRU has a module that hosts the uplink and downlink fiber optic connections to and from the upstream ICU.



Figure 2-1 MRU Main Modules

Exhibit C at 13. For example, the below photograph shows the fiber optic connection to the ICU that carries uplink and downlink signals to and from the MRU:



Figure 4-15 Fiber Connections Towards ICU

Exhibit C at 35. The MRU manual also shows several other connections to this module, such as a management port, external alarm connections, and RF expansion ports among others:

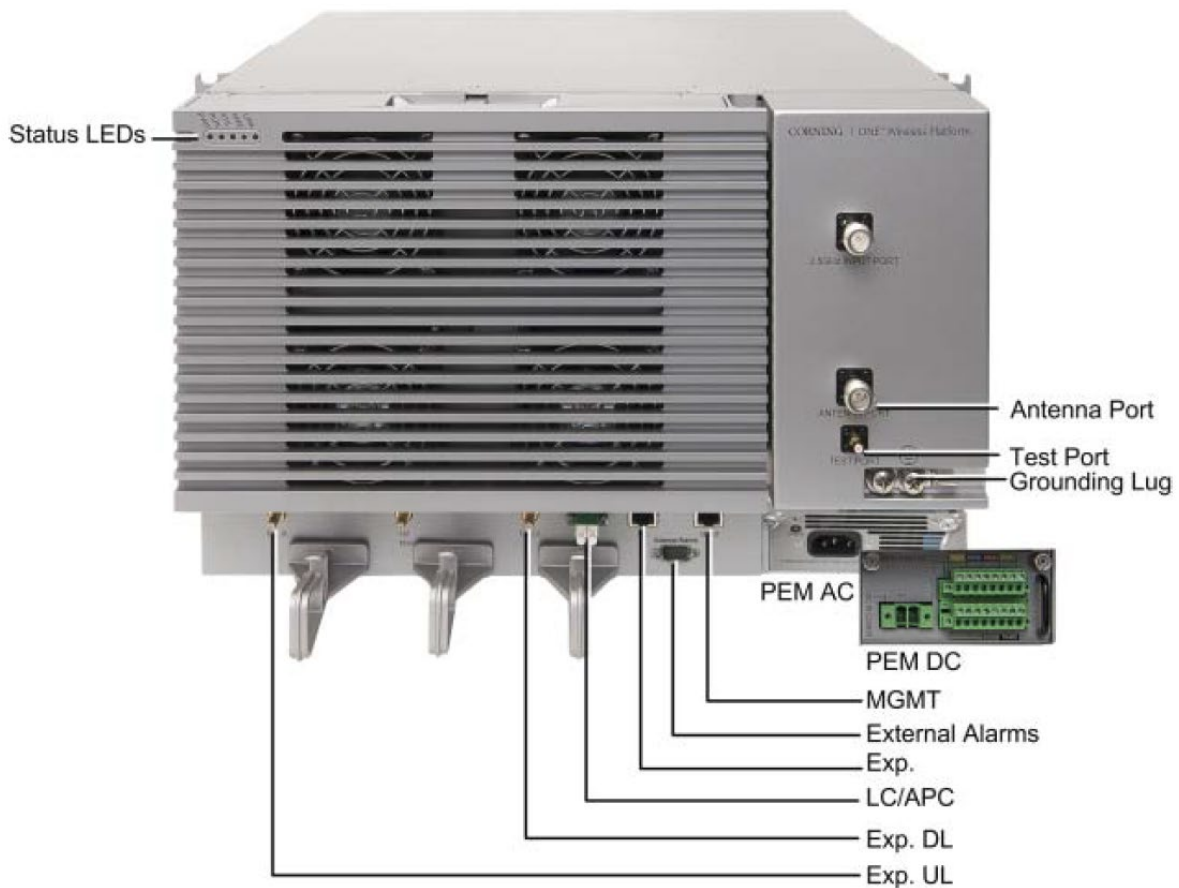


Figure 2-2. MRU External Interfaces

Exhibit C at 14. On information and belief, this module handles communication and management signals and distributes them to various band modules, indicated as “Power Amplifier Modules” above. As such, this module is a remotely reconfigurable access module configured to receive reconfiguration parameters from a remote location. Therefore, Corning’s ONE MRU meets limitation A of claim 1.

35. The Corning ONE MRU also meets all the requirements of limitation B of claim 1. Limitation B requires, “a plurality of band modules, each of the plurality of band modules having separately reconfigurable parameters in response to the reconfiguration parameters received from the at least one remotely reconfigurable access module, each of the plurality of band modules supporting one of a plurality of frequency bands of the radio frequency signals being transported”.

As shown above in Figure 2-1 of the MRU manual above, the MRU contains up to five band modules for each service, for example, LTE, ESMR800, PCS, AWS and WCS. Exhibit C at 13. As described in the MRU manual, each of these services operates in different frequency ranges, or bands, and has configurable parameters such as gain:

Service/Band	LTE 700 MHz		ESMR800/ CELL850 MHz		PCS 1900 MHz		AWS 2100 MHz		WCS 2300 MHz	
RF Parameter	DL	UL	DL	UL	DL	UL	DL	UL	DL	UL
Frequency Range (MHz)	729-746 746-756	699-716 777-787	862-869/ 869-894	817-824/ 824-849	1930-1995	1850-1915	2110-215 5	1710-1755	2350 - 2360	2305 - 2315
Max Output Power Per Antenna Port (dBm)	30		30		33		33		33	
Input Power (dBm)	0 - 37		0 - 37		0 - 37		0 - 37		0 - 37	
UL Gain Range (dB)		-19 to 15		-19 to 15		-19 to 15		-19 to 15		-19 to 15
Input IP3 (dBm) AGC OFF Typical		-5		-5		-5		-5		-5
Input IP3 (dBm) AGC ON Typical		5		5		5		5		5
SFDR* (dB)		60		64		64		60		60
Max Intermod Distortion [dBm]	≤ -13		≤ -13		≤ -13		≤ -13		≤ -13	
UL NF*(dB)		12		12		12		12		12
Gain Flatness/Ripple (dB)	±2.0		±2.0		±2.0		±2.0		±2.0	

*Typical for single Remote Access Unit

** SFDR calculated with BW of 1.23MHz for the CELL and PCS and with 5MHz for the LTE, AWS and WCS.

Exhibit C at 42. As such, the Corning ONE MRU meets limitation B of claim 1.

36. The Corning ONE MRU also meets all the requirements of limitation C1 of claim 1. Limitation C1 requires, “an interface adapted to provide” “electrical and mechanical connection for mounting of the plurality of band modules.” On information and believe, the modules appear to have electrical and mechanical connections to the chassis and modules of the MRU. For example, electrical power and communications are provided through the front of other modules in the MRU chassis and, on information and belief, are then connected to the band modules or Power

Amplifier Modules. Additionally, mechanical connections are made to secure the band modules into the MRU chassis. As such, Corning's ONE MRU meets limitation C1 of the '508 patent.

37. The Corning ONE MRU also meets all the requirements of limitation C2 of claim 1. Limitation C2 requires, "an interface adapted to provide" "bidirectional digital communication between the at least one remotely reconfigurable access module and each of the plurality of band modules." The MRU manual describes the management and control functions such as forwarding band module alarms to a monitoring system and controlling the output power of the band modules via SNMP.

- **Management and control** – alarm forward to NOC or standard element management system (EMS) via SNMP, software controlled output power and optical link auto gain control.

Exhibit C at 9. Additionally, the screenshot from management system provided in the Corning ONE Wireless Platform MRU brochure shows various MRU alarms including one for each band module in the history pane, and also a tab for setting various RF parameters for the band modules. *Corning ONE Wireless Platform MRU*, Exhibit D at 5. As such, the Corning ONE MRU meets limitation C2 of claim 1.

38. Accordingly, on information and belief, Corning's ONE MRU meets all the limitations of, and therefore infringes, at least claim 1 of the '508 patent.

39. As a result of Corning's infringement of the '508 patent, Dali has suffered and continues to suffer substantial injury and is entitled to recover all damages caused by Corning's infringement to the fullest extent permitted by the Patent Act, together with prejudgment interest and costs for Corning's wrongful conduct.

SECOND CAUSE OF ACTION
(PATENT INFRINGEMENT UNDER 35 U.S.C. § 271 of '766 PATENT)

40. Dali re-alleges and incorporates by reference all of the foregoing paragraphs.

41. On information and belief, Corning has infringed and continues to infringe, either literally or under the doctrine of equivalents, one or more claims, including at least claim 1, of the '766 patent in violation of 35 U.S.C. §§ 271 et seq., directly and/or indirectly, by making, using, importing, selling, and/or offering for sale certain equipment and systems relating to E-RAN small cell systems, such as SpiderCloud's currently advertised Services and Radio nodes. See <http://www.SpiderCloud.com/products>.

Direct Infringement

42. On information and belief, Corning has been and currently is directly infringing the '766 patent by using its products, including at least the SpiderCloud Services and Radio nodes under 35 U.S.C. § 271.

43. Claim 1 of the '766 patent recites the following:

[preamble] A method of determining a transmission power of a digital remote unit (DRU) in a distributed antenna system (DAS), the method comprising:

- a) setting a transmission power level for a DRU;
- b) determining a first key performance indicator related to a number of satisfied users at the transmission power;
- c) iteratively adjusting the transmission power level for the DRU to increase the first key performance indicator related to the number of satisfied users;
- d) determining a second key performance indicator related to a capacity for the number of satisfied users;
- e) iteratively adjusting the transmission power level for the DRU to increase the second key performance indicator related to the capacity for the number of satisfied users; and
- f) setting the transmission power level for the DRU at an iterated power level.

44. On information and belief, and based on publicly available information, at least Corning's SpiderCloud system satisfies each and every limitation of at least claim 1 of the '766 patent.

45. Corning's SpiderCloud system includes all the features of the preamble of claim 1 to the extent the preamble features are determined to be limiting. For example, Corning's SpiderCloud system provides a DAS:



<https://www.corning.com/catalog/coc/documents/brochures/LAN-2327-AEN.pdf>. SpiderCloud also provides multiple “digital remote units (DRUs).” According to the SpiderCloud product website, “multiple radio nodes are connected to the Services Node using standard Ethernet LAN infrastructure.” <http://www.SpiderCloud.com/products>. The “multiple radio nodes” referred to above are the “digital remote units (DRUs).” Additionally, SpiderCloud also provides a method for determining the transmission power for the radio nodes, i.e. DRUs:

Periodic Optimization and Self-Maintenance

While the system is in operational mode, a power optimization feature is used to periodically adjust the transmit power levels in order to achieve uniform coverage across the small cell deployment. The algorithm takes into account several factors:

- The interference level from macro networks as measured by the radio nodes
- The relative signal strength at which each radio node measures neighboring radio nodes
- Periodic signal quality measurements made by user devices across the network and reported back to the services node

The service node uses measurements collected over time to fine-tune the network. For example it might reduce the power level of a congested cell to decrease the number of users on that cell, while powering up lightly loaded cells. The system can also be configured to periodically monitor for changes in topology (added or deleted external and internal cells) and changes in the physical RF environment of the deployment area. For example, the system can be configured to go into scan mode during weekends, when no traffic is expected on the network.

<http://www.SpiderCloud.com/tech/son-auto-configuration>. Therefore, all of the features recited in the preamble are met by the SpiderCloud system.

46. Limitation a) of claim 1 requires, “setting a transmission power level for a DRU.” According to the below portion of SpiderCloud’s website, SpiderCloud’s “self-optimizing network” or “SON” feature sets the transmission power levels for radio nodes, i.e. DRUs:

SON Architecture and External Interfaces

The E-RAN’s SON capabilities include discovering the macro cells in the area, discovering the internal small cell topology, assigning UMTS primary scrambling codes and LTE physical cell identifier, setting maximum transmit power levels, and automatically configuring cell neighbor lists to make the system operational.

<http://www.SpiderCloud.com/tech/son-auto-configuration>. Therefore, the SpiderCloud system meets all the requirements of limitation a) of claim 1 of the ’766 patent.

47. Limitation b) of claim 1 requires, “determining a first key performance indicator related to a number of satisfied users at the transmission power.” As shown in paragraph 38 above, SpiderCloud’s SON feature causes the Service nodes to collect periodic signal quality measurements from user devices in order to “fine-tune the network.” As a result, SpiderCloud

practices all the requirements of limitation b) of claim 1 of the '766 patent.

48. Limitation c) of claim 1 requires, “iteratively adjusting the transmission power level for the DRU to increase the first key performance indicator related to the number of satisfied users.” As discussed above in connection with paragraphs 38-40, the SpiderCloud Services node collects signal quality measurements from user devices *periodically* and uses that information to fine-tune the network. One example provided on the SpiderCloud SON website states that “a power optimization feature is used to periodically adjust the transmit power levels in order to achieve uniform coverage across the small cell deployment.” <http://www.SpiderCloud.com/tech/son-auto-configuration>. The multiple references to “periodically” indicate that the power adjustments are iterative in nature. As a result, SpiderCloud practices limitation c) of claim 1 of the '766 patent.

49. Limitation d) of claim 1 requires, “determining a second key performance indicator related to a capacity for the number of satisfied users.” The SpiderCloud website regarding the SON feature states that one of the multiple measurements the algorithm takes into account is power level in congested cells, and may reduce the number of users in a particular cell based on the measurements. “The service node uses measurements collected over time to fine-tune the network. For example it might reduce the power level of a congested cell to decrease the number of users on that cell, while powering up lightly loaded cells.” <http://www.SpiderCloud.com/tech/son-auto-configuration>. Therefore, SpiderCloud practices limitation d) of claim 1 of the '766 patent.

50. Limitation e) of claim 1 requires, “iteratively adjusting the transmission power level for the DRU to increase the second key performance indicator related to the capacity for the number of satisfied users.” As described in paragraphs 41 and 42 above, the Services node “*periodically* adjust the transmit power levels” to achieve various system performance goals.

<http://www.SpiderCloud.com/tech/son-auto-configuration>. Therefore, SpiderCloud practices limitation e) of claim 1 of the '766 patent.

51. On information and belief, Corning employees and/or agents practice the infringing method of claim 1 of the '766 patent at least in connection with the process of testing and/or quality control relating to the SpiderCloud Services and Radio nodes.

52. Accordingly, on information and belief, Corning's SpiderCloud system meets all limitations of, and therefore Corning's use of the SpiderCloud system directly infringes at least claim 1 of the '766 patent.

Indirect Infringement

53. Dali re-alleges and incorporates by reference all of the foregoing paragraphs.

54. On information and belief, Corning has been and currently is also indirectly infringing the '766 patent by selling its products, including at least the SpiderCloud Services and Radio nodes, to third party customers whose use of the SpiderCloud Services and Radio nodes directly infringes the '766 patent under 35 U.S.C. § 271.

55. Corning has had specific knowledge of the '766 patent and that SpiderCloud Services and Radio nodes infringe the '766 patent since at least January 8, 2020, when Basem Anshasi, Dali's Chief Operating Officer informed Kim Hartwell, SVP and Chief Commercial Officer at Corning Optical Communications, via email that Dali had filed a patent infringement lawsuit against Corning pending in the Western District of North Carolina, case number 3:19-cv-00714 (the "WDNC Suit").

56. The WDNC Suit alleged, among other things, that use of the SpiderCloud Services and Radio nodes infringe the '766 patent.

57. Between January and April 2020, representatives for Dali and Corning exchanged

emails, met in person, and conducted conference calls during which Corning's infringement of the '766 patent was discussed.

58. On information and belief, Corning sells the SpiderCloud Services and Radio nodes to third party end users with the knowledge and intention that the customers' use of the SpiderCloud Services and Radio nodes will directly infringe the '766 patent.

59. On information and belief, Corning's customers directly infringe the '766 patent by using the SpiderCloud Services and Radio nodes.

60. On information and belief, Corning's SpiderCloud Services and Radio nodes have no substantial noninfringing use.

61. Accordingly, on information and belief, Corning's sales of SpiderCloud Services and Radio nodes indirectly infringe at least claim 1 of the '766 patent.

Willful Infringement

62. Dali re-alleges and incorporates by reference all of the foregoing paragraphs.

63. As demonstrated above, Corning has had specific knowledge of the '766 patent and infringement thereof by the SpiderCloud Services and Radio nodes since at least January 2020.

64. On information and belief, after acquiring specific knowledge of the '766 patent and infringement thereof by the SpiderCloud Services and Radio nodes, Corning continued to use and to market and sell the SpiderCloud Services and Radio nodes to third parties.

65. On information and belief, Corning knew, or should have known, that its conduct as described above, amounted to infringement of the '766 patent.

* * *

66. As a result of Corning's direct, indirect, and willful infringement of the '766 patent, Dali has suffered and continues to suffer substantial injury and is entitled to recover all damages caused by Corning's infringement to the fullest extent permitted by the Patent Act, together with

prejudgment interest and costs for Corning's wrongful conduct.

PRAYER FOR RELIEF

WHEREFORE, Dali respectfully requests judgment against Corning as follows:

A. That the Court enter judgment for Dali on all causes of action asserted in this Complaint;

B. That the Court enter judgment in favor of Dali and against Corning for monetary damages to compensate it for Corning's infringement of the Patents-in-Suit pursuant to 35 U.S.C. § 284, including costs and prejudgment interest as allowed by law;

C. That the Court enter judgment in favor of Dali and against Corning for increased damages pursuant to 35 U.S.C. § 284 for Corning's willful infringement of the '766 patent;

D. That the Court enter judgment in favor of Dali and against Corning for accounting and/or supplemental damages for all damages occurring after any discovery cutoff and through the Court's entry of final judgment;

E. That the Court enter judgment that this case is exceptional under 35 U.S.C. § 285 and enter an award to Dali of its costs and attorneys' fees; and

F. That the Court award Dali all further relief as the Court deems just and proper.

JURY DEMAND

Dali requests that all claims and causes of action raised in this Complaint against Corning be tried to a jury to the fullest extent possible.

Date: September 9, 2020

Respectfully submitted,

LAW OFFICE OF JOSEPH M. ABRAHAM, PLLC

/s/ Joseph M. Abraham

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EXHIBIT A



US009826508B2

(12) **United States Patent**
Lemson et al.

(10) **Patent No.:** **US 9,826,508 B2**

(45) **Date of Patent:** ***Nov. 21, 2017**

(54) **NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM**

(71) Applicant: **DALI SYSTEMS CO. LTD.**, George Town, Grand Cayman (KY)

(72) Inventors: **Paul Lemson**, Woodinville, WA (US); **Shawn Patrick Stapleton**, Burnaby (CA); **Sasa Trajkovic**, Burnaby (CA)

(73) Assignee: **Dali Systems Co. Ltd.**, George Town (KY)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 108 days.

This patent is subject to a terminal disclaimer.

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(Continued)

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H04B 1/18 (2006.01)

H04B 1/40 (2015.01)

(52) **U.S. Cl.**

CPC **H04W 72/04** (2013.01); **H04B 1/18** (2013.01); **H04B 1/40** (2013.01)

(58) **Field of Classification Search**

CPC H04B 1/18; H04B 1/40; H04W 72/04
See application file for complete search history.

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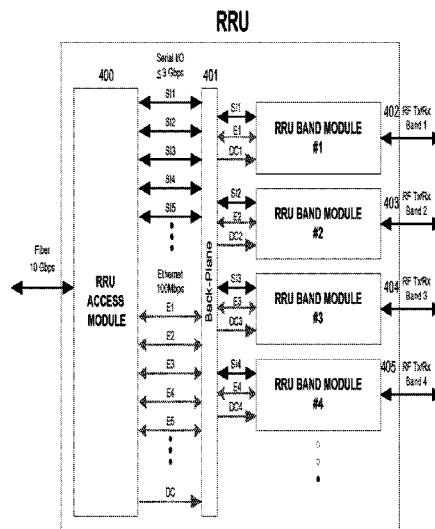
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(57) **ABSTRACT**

A remote radio head unit (RRU) system for achieving high data rate communications in a Distributed Antenna System is disclosed. The Distributed Antenna System is configured as a Neutral Host enabling multiple operators to exist on one DAS system. The present disclosure enables a remote radio head unit to be field reconfigurable and support multi-modulation schemes (modulation-independent), multi-carriers, multi-frequency bands and multi-channels. As a result, the remote radio head system is particularly suitable for wireless transmission systems, such as base-stations, repeaters, and indoor signal coverage systems.

12 Claims, 6 Drawing Sheets



Remote Radio Head Unit High Level System

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Page 2

Related U.S. Application Data

(60) Provisional application No. 61/374,593, filed on Aug. 17, 2010.

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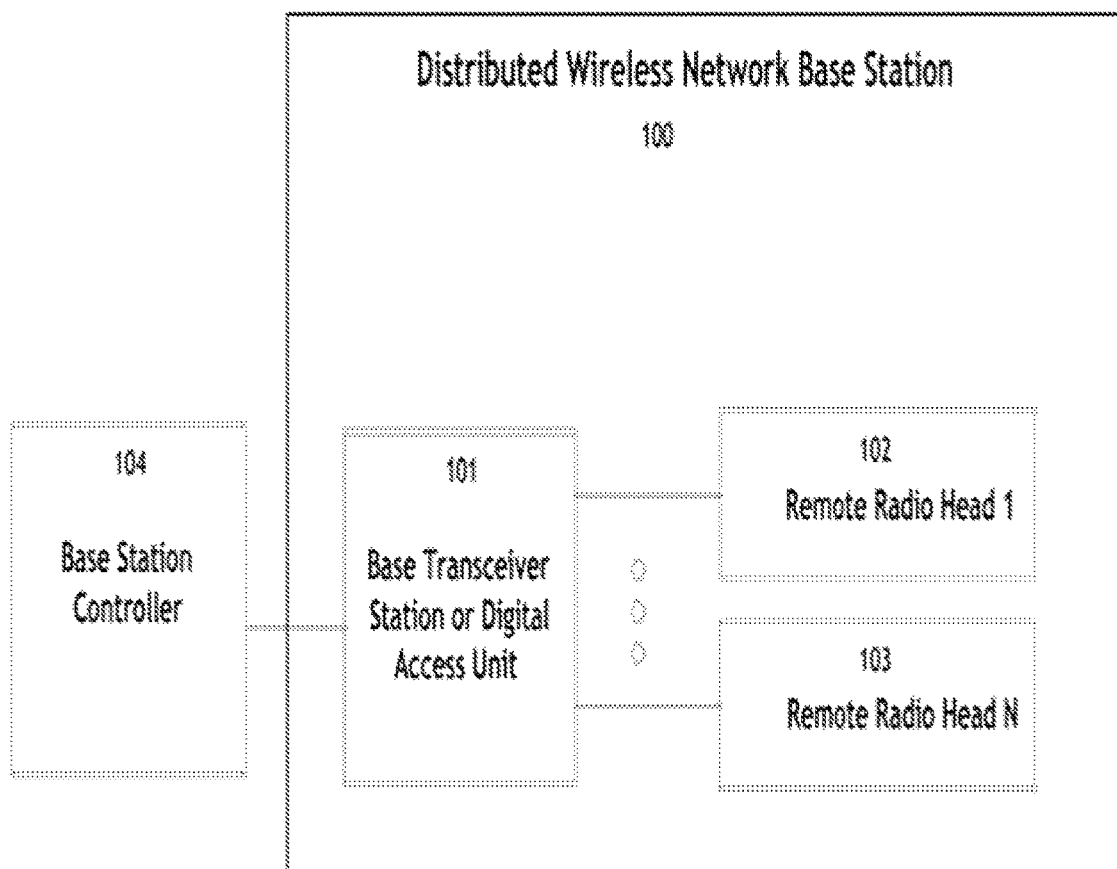


FIG. 1: PRIOR ART

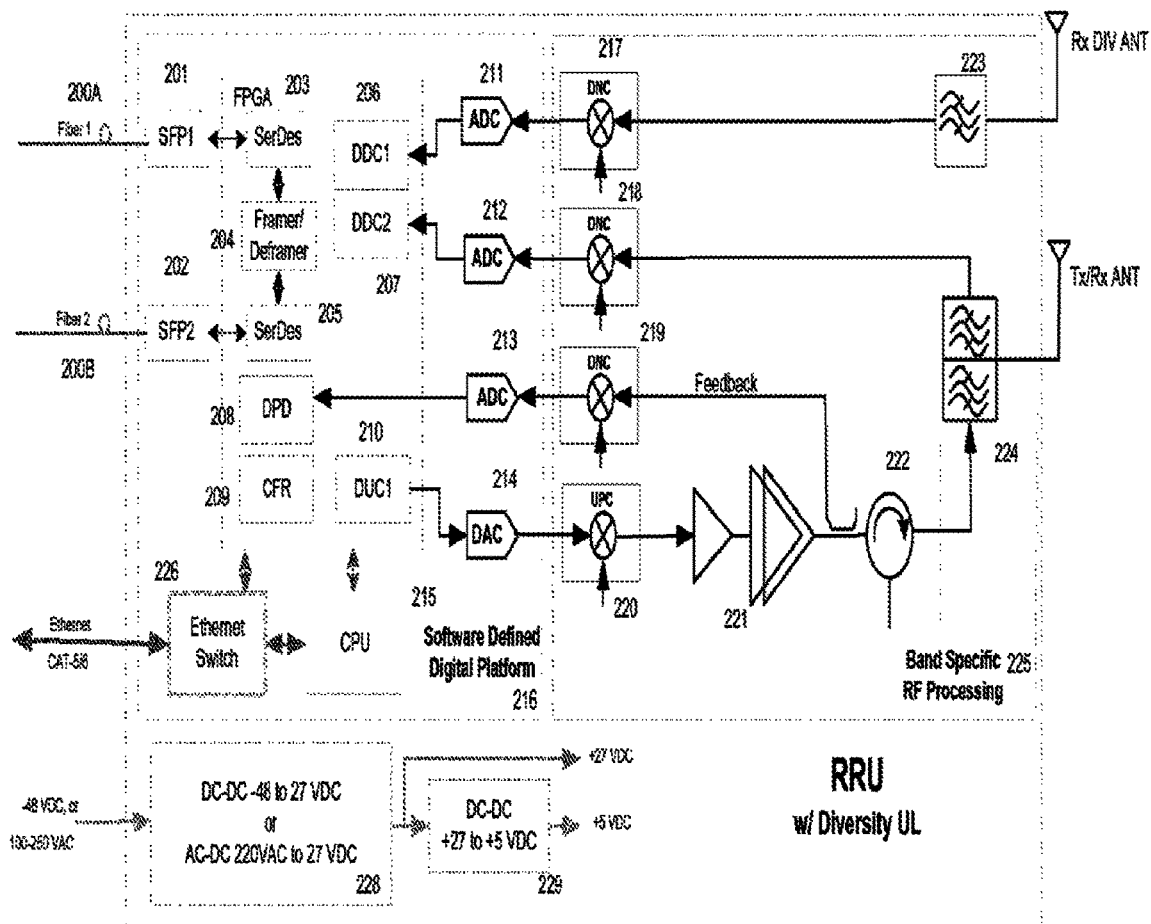
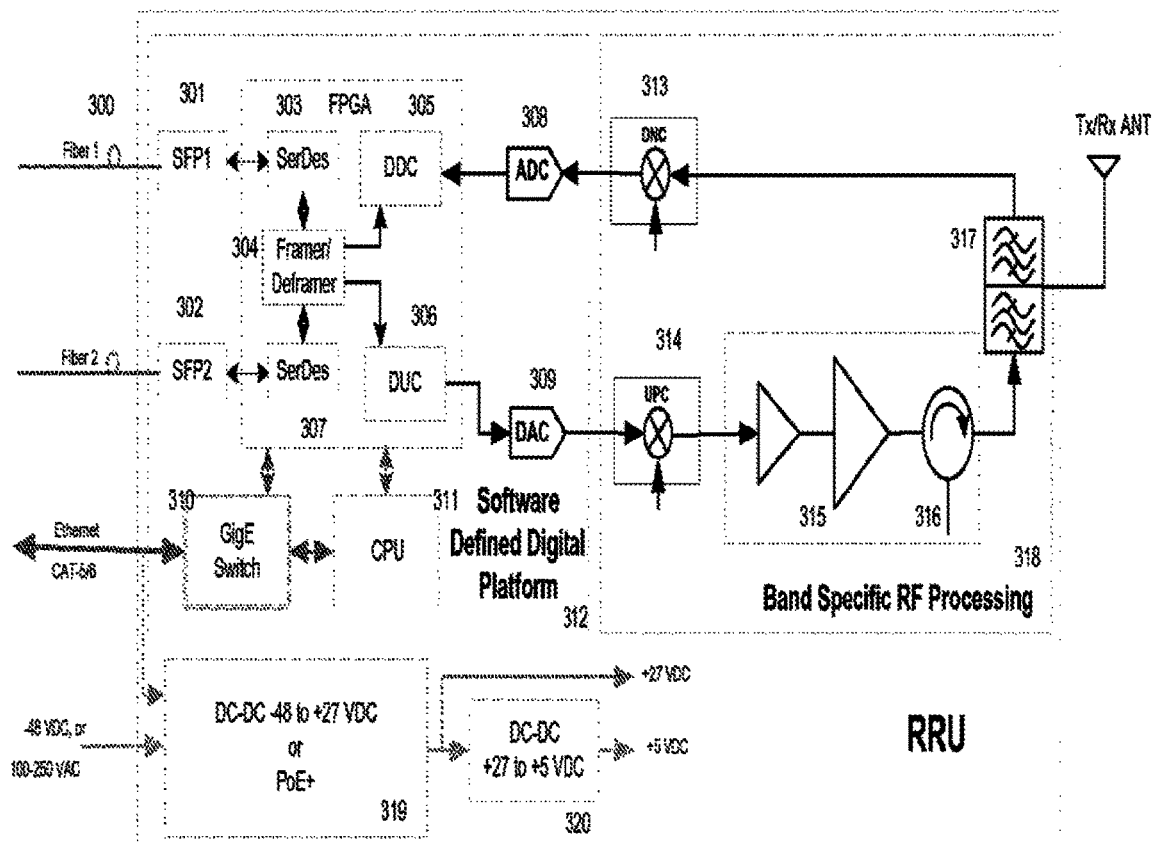


FIG. 2: Remote Radio Head Unit

**FIG. 3: Remote Radio Head Unit**

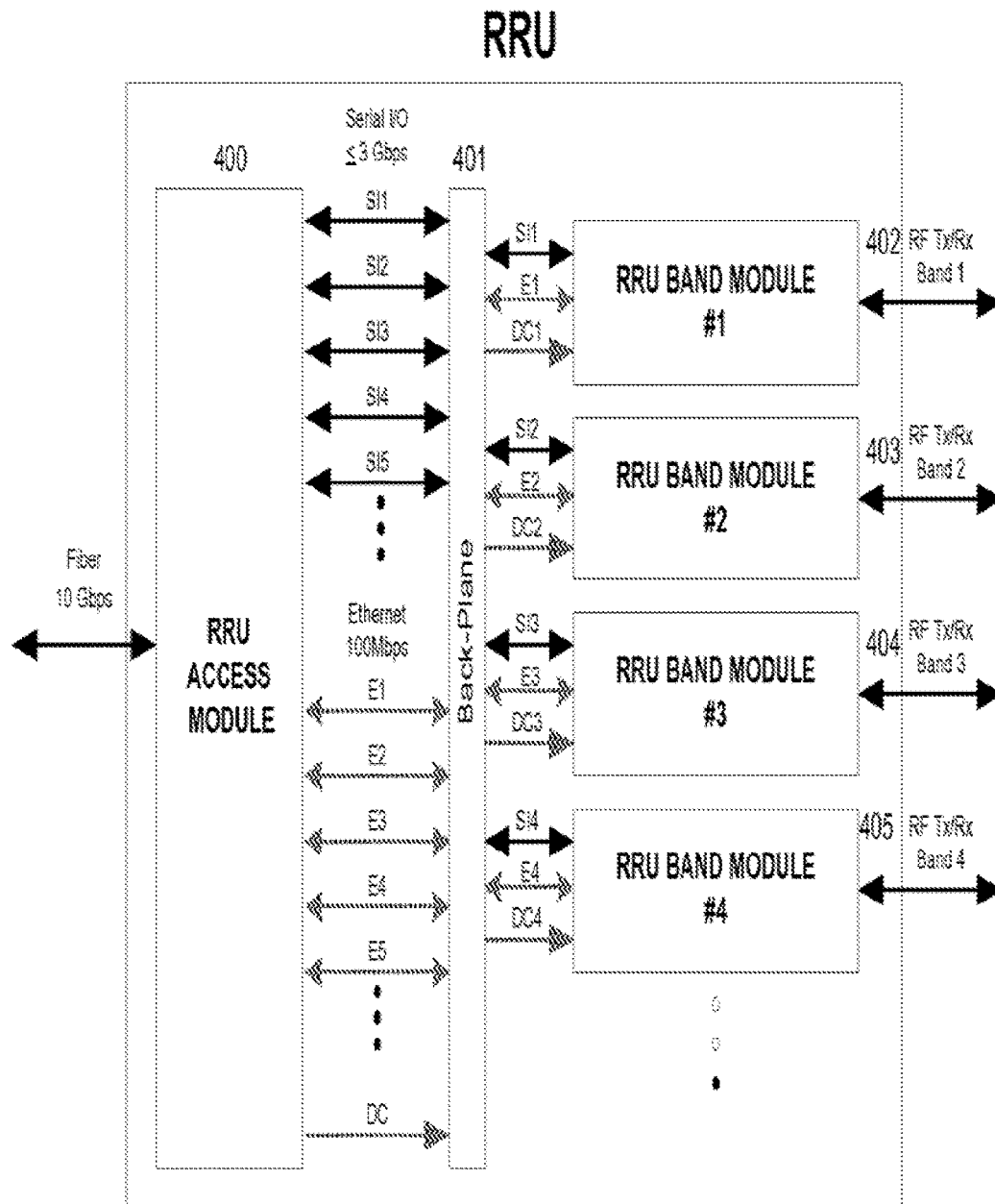


FIG. 4: Remote Radio Head Unit High Level System

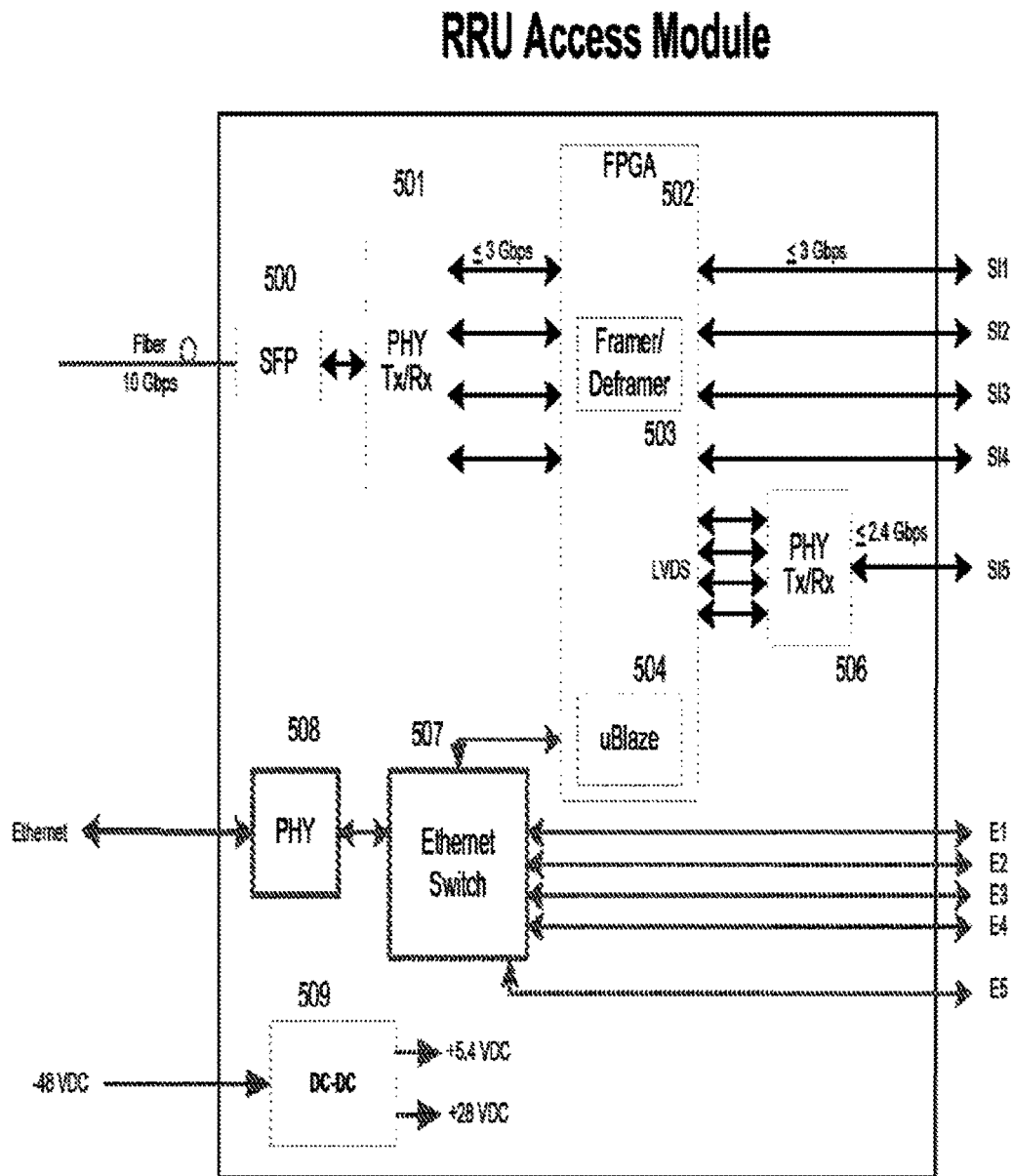
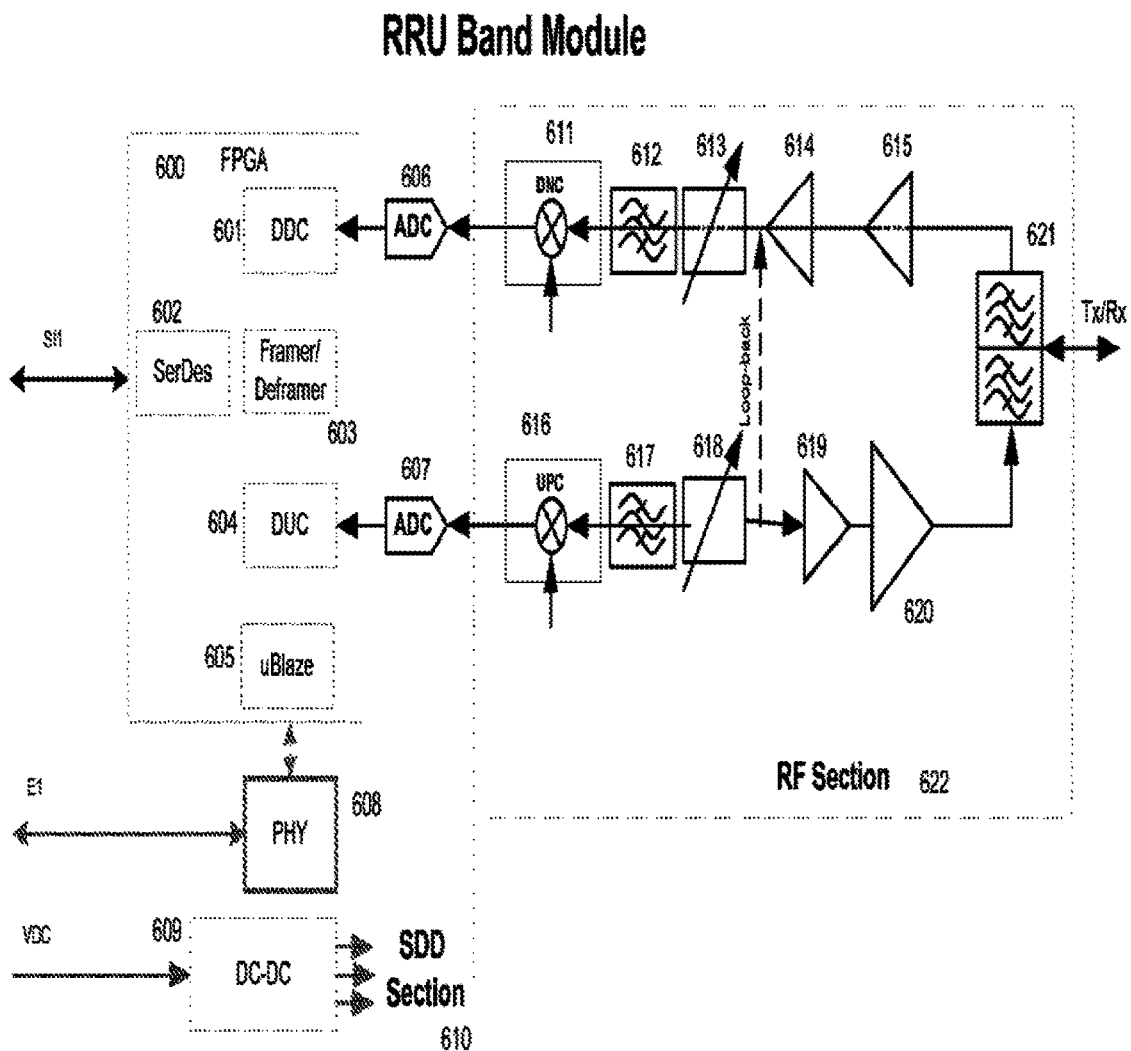


FIG. 5: Remote Radio Head Unit Access Module

**FIG. 6: Remote Radio Head Unit Band Module**

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NEUTRAL HOST ARCHITECTURE FOR A DISTRIBUTED ANTENNA SYSTEM

RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No.: 13/211,236, filed Aug. 16, 2011, now U.S. Pat. No. 8,848,766; which claims priority to U.S. Provisional Patent Application No. 61/374,593, filed on Aug. 17, 2010. The disclosures of each are hereby incorporated by reference in their entirety for all purposes.

TECHNICAL FIELD

The present invention generally relates to wireless communication systems employing Distributed Antenna Systems (DAS). More specifically, the present invention relates to a DAS which is part of a distributed wireless network base station in which all radio-related functions that provide network coverage and/or capacity for a given area are contained in a small single unit that can be deployed in a location remote from the remaining distributed wireless network base station unit or units which are not performing radio-related functions. Multi-mode radios capable of operating according to GSM, HSPA, LTE, TD-SCDMA, UMTS and WiMAX standards with advanced software configurability are features in the deployment of more flexible and energy-efficient radio networks. The present invention can also serve multiple operators and multi-frequency bands per operator within a single DAS to reduce the costs associated with radio network equipment and radio network deployment.

BACKGROUND OF THE INVENTION

Wireless and mobile network operators face the continuing challenge of building networks that effectively manage high data-traffic growth rates. Mobility and an increased level of multimedia content for end users requires end-to-end network adaptations that support both new services and the increased demand for broadband and flat-rate Internet access. In addition, network operators must consider the most cost-effective evolution of the networks towards 4G and other advanced network capabilities. Wireless and mobile technology standards are evolving towards higher bandwidth requirements for both peak rates and cell throughput growth. The latest standards supporting these higher bandwidth requirements are HSPA+, WiMAX, TD-SCDMA and LTE. The network upgrades required to deploy networks based on these standards must deal with the limited availability of new spectrum, leverage existing spectrum, and ensure operation of all desired wireless technology standards. The processes of scarce resource optimization while ensuring a future-proof implementation must both take place at the same time during the transition phase, which usually spans many years and thus can encompass numerous future developments. Distributed open base station architecture concepts have evolved in parallel with the evolution of the various technology standards to provide a flexible, lower-cost, and more scalable modular environment for managing the radio access evolution. Such advanced base station architectures can generally be appreciated from FIG. 1 [PRIOR ART], which shows an architecture for a prior art Distributed Wireless Network Base Station. In FIG. 1, **100** is a depiction of a Distributed Wireless Network Base Station. The Base Transceiver Station (BTS) or Digital Access Unit (DAU) **101** coordinates the communication

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between the Remote Radio Head Units **102**, **103** and the Base Station Controller (BSC). The BTS communicates with multiple Remote Radio Heads via optical fiber. For example, the Open Base Station Architecture Initiative (OBSAI), the Common Public Radio Interface (CPRI), and the IR Interface standards introduced publicly-defined interfaces separating the Base Transceiver Station (BTS) or Digital Access Unit and the remote radio head unit (RRU) parts of a base station by employing optical fiber transport.

The RRU concept constitutes a fundamental part of an advanced state-of-the-art base station architecture. RRU-based system implementation is driven by the need to achieve consistent reductions in both Capital Expenses (CAPEX) and Operating Expenses (OPEX), and enable a more optimized, energy-efficient, and greener base deployment. An existing application employs an architecture where a 2G/3G/4G base station is connected to RRUs over multiple optical fibers. Either CPRI, OBSAI or IR Interfaces may be used to carry RF data to the RRUs to cover a sectorized radio network coverage area corresponding to a radio cell site. A typical implementation for a three-sector cell employs three RRU's. The RRU incorporates a large number of digital interfacing and processing functions. However, commercially available RRU's are power inefficient, costly and inflexible. Their poor DC-to-RF power conversion insures that they will need to have a large mechanical housing to help dissipate the heat generated. The demands from wireless service providers for future RRU's also includes greater flexibility in the RRU platform, which is not presently available. As standards evolve, there will be a need for multi-band RRUs that can accommodate two or more operators using a single wideband power amplifier. Co-locating multiple operators in one DAS system would reduce the infrastructure costs and centralize the Remote Monitoring Function of multiple Operators on the Network. To accommodate multiple operators and multiple bands per operator would require a very high optical data rate to the RRUs which is not achievable with prior art designs.

BRIEF SUMMARY OF THE INVENTION

The present invention substantially overcomes the limitations of the prior art discussed above. Accordingly, it is an object of the present invention to provide a high performance, cost-effective DAS system, architecture and method for an RRU-based approach which enables each of multiple operators to use multi-frequency bands. The present disclosure enables a RRU to be field reconfigurable, as presented in U.S. Patent application 61/172,642 (DW-1016P), filed Apr. 24, 2009, entitled Remotely Reconfigurable Power Amplifier System and Method, U.S. patent application Ser. No. 12/108,502 (DW1011U), filed Apr. 23, 2008, entitled Digital Hybrid Mode Power Amplifier System, U.S. Patent application 61/288,838 (DW1018P), filed Dec. 21, 2009, entitled Multi-band Wideband Power Amplifier Digital Predistortion System, U.S. Patent application 61/288,840 (DW1019P), filed Dec. 21, 2009, entitled Remote Radio Head Unit with Wideband Power Amplifier and Method, U.S. Patent application 61/288,844 (DW1020P), filed Dec. 21, 2009, entitled Modulation Agnostic Digital Hybrid Mode Power Amplifier System, and U.S. Patent application 61/288,847 (DW1021P), filed Dec. 21, 2009, entitled High Efficiency Remotely Reconfigurable Remote Radio Head Unit System and Method for Wireless Communications incorporated herein by reference. In addition, the system and method of the present invention supports multi-modulation schemes (modulation-independent), multi-carriers, multi-

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frequency bands, and multi-channels. To achieve the above objects, the present invention maximizes the data rate to the Remote Radio Head Unit in a cost effective architecture. FIGS. 2 and 3 depict a low power RRU and high power RRU. The RRUs depicted in FIGS. 2 and 3 can be extended to a multi-band and multi-channel configuration. Multi-band implies more than two frequency bands and multi-channel implies more than one output to an antenna system. Various embodiments of the invention are disclosed.

An embodiment of the present invention utilizes a RRU Access Module. The objective of the access module is to de-multiplex and multiplex high speed data to achieve aggregate data rates sufficient for operation of a plurality of RRU Band Modules which are geographically distributed. An alternative embodiment of the present invention utilizes the physical separation of the RRU Band Modules from the RRU Access Module using an optical fiber cable, Ethernet cables, RF cable and any other form of connection between the modules. In an alternative embodiment, a Remote Radio Unit comprised of one or more RRU Band Modules may be collocated with the antenna or antennas. In a further alternative embodiment, the RRU Access Module can also supply DC power on the interconnection cabling. In other aspects of the invention, control and measurement algorithms are implemented to permit improved network deployment, network management, and optimization.

Applications of the present invention are suitable to be employed with all wireless base-stations, remote radio heads, distributed base stations, distributed antenna systems, access points, repeaters, distributed repeaters, optical repeaters, digital repeaters, mobile equipment and wireless terminals, portable wireless devices, and other wireless communication systems such as microwave and satellite communications. The present invention is also field upgradable through a link such as an Ethernet connection to a remote computing center.

Appendix I is a glossary of terms used herein, including acronyms.

BRIEF DESCRIPTION OF THE DRAWINGS

Further objects and advantages of the present invention can be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. 1 [PRIOR ART] is a block diagram showing the basic structure of a prior art Distributed Wireless Base Station system.

FIG. 2 is a block diagram showing a multi-channel High Power Remote Radio Head Unit according to one embodiment of the present invention.

FIG. 3 is a block diagram multi-channel High Power Remote Radio Head Unit according to one embodiment of the present invention.

FIG. 4 is a block diagram of a Remote Radio Head Unit high level system of the present invention.

FIG. 5 is a block diagram of the Remote Radio Head Unit Access Module of the present invention.

FIG. 6 is a Remote Radio Head Unit Band Module according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is a novel Distributed Antenna System that utilizes a high speed Remote Radio Head Unit Access Module interconnected with Remote Radio Head Unit Band Module.

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An embodiment of a Remote Radio Head Unit in accordance with the invention is shown in FIG. 2. Fiber 1, indicated at 200A, is a high speed fiber cable that transports data between the BTS and the Remote Radio Head Unit. Fiber 2, indicated at 200B, is used to daisy chain other remote radio head units which are thereby interconnected to the BTS or DAU. The software-defined digital platform 216 performs baseband signal processing, typically in an FPGA or equivalent. Building block 203 is a Serializer/Deserializer. The deserializer portion extracts the serial input bit stream from the optical fiber 201 and converts it into a parallel bit stream. The serializer portion performs the inverse operation for sending data from the Remote Radio Head Unit to the BTS. In an embodiment, the two distinct bit streams communicate with the BTS using different optical wavelengths over one fiber, although multiple fibers can be used in alternative arrangements. The deframer 204 deciphers the structure of the incoming bit stream and sends the deframed data to the Crest Factor Reduction Algorithm 209. The Crest Factor Reduction block 209 reduces the Peak-to-Average Ratio of the incoming signal so as to improve the Power amplifier DC-to-RF conversion efficiency. The waveform is then presented to the Digital Predistorter block 208. The digital predistorter compensates for the nonlinearities of the Power Amplifier 221 in an adaptive feedback loop. Digital Upconverter 210 filters and digitally translates the deframed signal to an IF frequency. The Framer 204 takes the data from the two digital downconverters 206, 207 and packs it into a Frame for transmission to the BTS over the optical fiber 201. Elements 211 and 212 are Analog to Digital converters that are used to translate the two analog receive signals into digital signals. The receiver comprises a diversity branch which contains a downconverter 217 and a Band Pass Filter 223. The main branch has a receiver path comprised of a duplexer 224 and a downconverter 218. In some embodiments, one or both downconverters 217 and 218 can have an integral uplink low-noise amplifier.

The power amplifier has an output coupler for extracting a replica of the output signal in the feedback path. The feedback signal is frequency-translated by downconverter 219 to either an IF frequency or baseband and presented to an Analog to Digital converter 213. This feedback signal is used in an adaptive loop for performing Digital Predistortion to compensate for any nonlinearities created by the power amplifier.

The Ethernet cable is used to locally communicate with the Remote Radio Head Unit. Switch 226 is used to allow easy access to either the FPGA or the CPU. DC power converters 228 and 229 are used to obtain the desired DC voltages for the Remote Radio Head Unit. Either an external voltage can be connected directly into the RRU or the DC power may be supplied through the Ethernet cable.

Although the description of the instant embodiment is directed to an application where a second optical fiber connection provides a capability for daisy chaining to other Remote Radio Head Units, an alternative embodiment provides multiple optical fiber connections to support a modified "hybrid star" configuration for appropriate applications which dictate this particular optical transport network configuration.

FIG. 3 depicts a remote radio head unit. In at least some designs, this architecture offers benefits when the RF output power is relatively low. In the embodiment shown in FIG. 3, digital predistortion and crest factor reduction are not employed as was the case in FIG. 2. Even though this topology shows a non-diversity configuration, a diversity receive branch can be added along with an additional

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transmitter path for development of a Multiple Input Multiple Output (MIMO) Remote Radio Head Unit.

The Remote Radio Head Unit high level system is shown in FIG. 4. It comprises a Remote Radio Head Unit Access Module **400** which communicates directly with the BTS or DAU. The function of the Remote Radio Head Unit Access Module **400** is to route the high speed data (at any desired speed, e.g., such as 10 Gbps as illustrated in FIG. 4) (the “Data Speed”) to the multiple Remote Radio Head Unit Band Modules and allows for local communications with them via Ethernet. A backplane **401** is used to interconnect the Remote Radio Head Unit Access Module **400** with the various Remote Radio Head Unit Band Modules **402, 403, 404, 405** at any speed lower than the Data Speed (e.g., less than or equal to 3 Gbps as illustrated in FIG. 4). The output ports of the Remote Radio Head Unit Band Modules are combined and sent to an antenna for transmission. An alternative embodiment is described as follows. Although the description of instant embodiment is directed to applications for up to four Remote Radio Head Unit Band Modules, an alternative embodiment involves feeding a much larger quantity of Remote Radio Head Unit Band Modules with signals of various bandwidths at various frequency bands covering multiple octaves of frequency range, to support a wide range of applications including location-based services, mobile internet, public safety communications, private enterprise telecommunications and broadband, and other wireless applications. The system can in theory support an infinite quantity of RRUs. Also, the Remote Radio Head Unit Band Modules may be set up remotely to have RF power values selected based on the specific desired applications as well as location-specific radio signal propagation factors. A further alternative embodiment leverages the flexibility of the architecture shown in FIG. 4 to provide a capability known as Flexible Simulcast. With Flexible Simulcast, the amount of radio resources (such as RF carriers, CDMA codes or TDMA time slots) assigned to a particular RRU or group of RRUs by each RRU Access Module can be set via software control to meet desired capacity and throughput objectives or wireless subscriber needs.

The detailed topology of the Remote Radio Head Unit Access Module is shown in FIG. 5. It comprises a Small form Factor Pluggable optic transceiver (SFP) **500** which operates on two distinct wavelengths, one for communicating from the BTS to the Remote Radio Head Unit Access Module and the other for communicating in the opposite direction. The SFP contains a Laser Diode for converting the electronic signal to an optical signal and an Optical detector for converting the optical signal into an electronic signal. A multiplexer/demultiplexer **501** converts the high speed data to multiple lower speed data paths for delivery to a FPGA **502**. The multiplexer/demultiplexer **501** performs the opposite function when data is being sent back to the BTS or DAU. The framer/deframer **503** routes the data to the appropriate Remote Radio Head Unit Band Modules. An additional multiplexer/demultiplexer **506** allows for further expansion of lower speed Remote Radio Head Units. The number of Remote Radio Head units is only limited by the capability of the FPGA. Local communication with the Remote Radio Head Unit’s Access Module’s FPGA or the individual Remote Radio Head Unit Band Modules is via an Ethernet connection **508**. Although the description of this embodiment is mainly directed to an application where a BTS or DAU (or multiple BTS or DAU) feeds the Remote Radio Head Unit Access Module, an alternative embodiment is described as follows. The alternative embodiment is one

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where the digital optical signals fed to the Remote Radio Head Unit Access Module may be generated by an RF-to-Digital interface which receives RF signals by means of one or more antennas directed to one or more base stations located at some distance from the Remote Radio Head Unit Access Module. A further alternative embodiment is one where the digital signals fed to the Remote Radio Head Unit Access Module may be generated in a combination of ways; some may be generated by an RF-to-Digital interface and some may be generated by a BTS or DAU. Some neutral host applications gain an advantage with regard to cost-effectiveness from employing this further alternative embodiment. Although the optical signals fed to the Remote Radio Head Unit Access Module described in the preferred and alternative embodiments are digital, the optical signals are not limited to digital, and can be analog or a combination of analog and digital. A further alternative embodiment employs transport on one or multiple optical wavelengths fed to the Remote Radio Head Unit Access Module.

The Remote Radio Head Unit Band Module is shown in FIG. 6. It comprises a Software Defined Digital (SDD) section **610** and an RF section **622**. An alternative embodiment employs a Remote Antenna Unit comprising a broadband antenna with RRU Band Module Combiner and multiple plug-in module slots, into which multiple RRU Band Modules intended for operation in different frequency bands are inserted. To provide an overall compact unit with low visual impact, this embodiment employs RRU Band Modules which each have a physically small form factor. One example of a suitably small form factor for the RRU Band Module is the PCMCIA module format. A further alternative embodiment employs RRU Band Modules where each has an integral antenna, and the embodiment does not require a common antenna shared by multiple RRU Band Modules.

In summary, the Neutral Host Distributed Antenna System (NHDAS) of the present invention enables the use of remote radio heads for multi-operator multi-band configurations, which subsequently saves hardware resources and reduces costs. The NHDAS system is also reconfigurable and remotely field-programmable since the algorithms can be adjusted like software in the digital processor at any time.

Moreover, the NHDAS system is flexible with regard to being able to support various modulation schemes such as QPSK, QAM, OFDM, etc. in CDMA, TD-SCDMA, GSM, WCDMA, CDMA2000, LTE and wireless LAN systems. This means that the NHDAS system is capable of supporting multi-modulation schemes, multi-bands and multi-operators.

Although the present invention has been described with reference to the preferred embodiments, it will be understood that the invention is not limited to the details described thereof. Various substitutions and modifications have been suggested in the foregoing description, and others will occur to those of ordinary skill in the art. Therefore, all such substitutions and modifications are intended to be embraced within the scope of the invention as defined in the appended claims.

What is claimed is:

1. A remotely reconfigurable remote radio head unit for transporting radio frequency signals, the remotely reconfigurable remote radio head unit comprising:

at least one remotely reconfigurable access module adapted to receive reconfiguration parameters from a remote location,

a plurality of band modules, each of the plurality of band modules having separately reconfigurable parameters in response to the reconfiguration parameters received

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from the at least one remotely reconfigurable access module, each of the plurality of band modules supporting one of a plurality of frequency bands of the radio frequency signals being transported, and

an interface adapted to provide:

electrical and mechanical connection for mounting of the plurality of band modules; and

bidirectional digital communication between the at least one remotely reconfigurable access module and each of the plurality of band modules.

2. The remotely reconfigurable remote radio head unit of claim 1 wherein the separately reconfigurable parameters comprise at least one of an operator, a frequency, or a carrier.

3. The remotely reconfigurable remote radio head unit of claim 2 wherein each of the plurality of band modules further comprises a field programmable gate array for storing the separately reconfigurable parameters for that band module.

4. The remotely reconfigurable remote radio head unit of claim 1 wherein each of the plurality of band modules further comprises a framer, deframer, serializer, and deserializer.

5. The remotely reconfigurable remote radio head unit of claim 1 wherein each of the plurality of band modules further comprises one or more power amplifiers.

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6. The remotely reconfigurable remote radio head unit of claim 5 wherein each of the plurality of band modules further comprises one or more digital predistorters.

7. The remotely reconfigurable remote radio head unit of claim 1 further comprising a crest factor reduction algorithm operable to reduce a peak-to-average ratio signature of an incoming signal.

8. The remotely reconfigurable remote radio head unit of claim 1 further comprising at least one integral uplink low-noise amplifier.

9. The remotely reconfigurable remote radio head unit of claim 1 wherein the at least one remotely reconfigurable access module is disposed in a modified hybrid star configuration.

10. The remotely reconfigurable remote radio head unit of claim 1 further comprising radio resources operable to provide a Flexible Simulcast capability.

11. The remotely reconfigurable remote radio head unit of claim 1 wherein the at least one remotely reconfigurable access module comprises a small form factor pluggable optic transceiver configured to operate on at least two distinct wavelengths.

12. The remotely reconfigurable remote radio head unit of claim 1 wherein each of the plurality of band modules comprises a software configurable digital section and a radio frequency section.

* * * * *

EXHIBIT B



US009769766B2

(12) **United States Patent**
Hejazi et al.

(10) **Patent No.:** **US 9,769,766 B2**
(45) **Date of Patent:** ***Sep. 19, 2017**

(54) **SELF-OPTIMIZING DISTRIBUTED ANTENNA SYSTEM USING SOFT FREQUENCY REUSE**

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(73) Assignee: **Dali Systems Co. Ltd.**, George Town (KY)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(22) Filed: **May 13, 2016**

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(Continued)

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H04W 52/24 (2009.01)

(Continued)

(52) **U.S. Cl.**

CPC **H04W 52/243** (2013.01); **H04L 5/0023** (2013.01); **H04L 5/0032** (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC ... H04L 5/0023; H04L 5/0032; H04L 5/0073;
H04W 52/243; H04W 52/346

See application file for complete search history.

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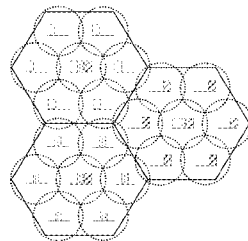
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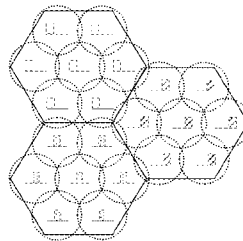
(57) **ABSTRACT**

A method of determining a carrier power in a communications system including a processor includes a) setting a power differential between a reference carrier and one or more carriers, b) measuring a number of satisfied users at the power differential, and c) measuring a capacity for the satisfied users at the power differential. The method also includes d) increasing the power differential by a predetermined amount and e) determining, using the processor, that the number of satisfied users at the increased power differential is greater than or equal to the number of satisfied users at the power differential. The method further includes f) repeating a)-c) and g) setting the carrier power at an iterated power level.

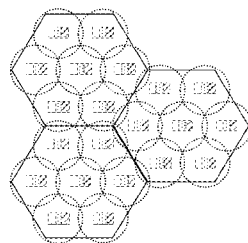
11 Claims, 14 Drawing Sheets



(a) DAS - Soft Frequency Reuses



(b) DAS - Hard Frequency Reuses



(c) DAS - Full Frequency Reuses



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Related U.S. Application Data

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H04L 5/00 (2006.01)
H04W 52/34 (2009.01)
H04W 72/04 (2009.01)
- (52) **U.S. Cl.**
 CPC *H04L 5/0073* (2013.01); *H04W 52/346*
 (2013.01); *H04W 72/0473* (2013.01)

- (56) **References Cited**

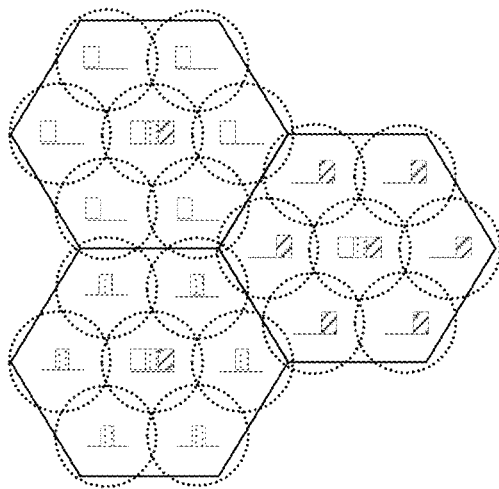
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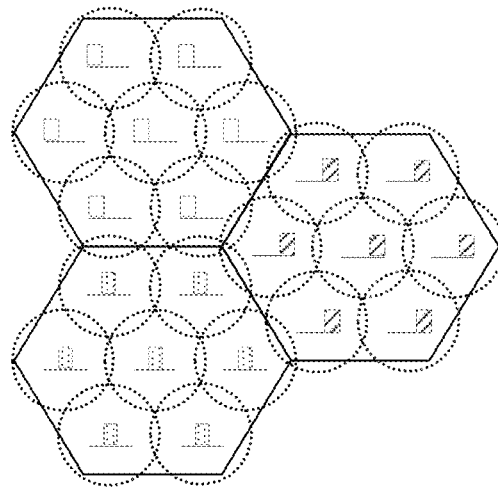
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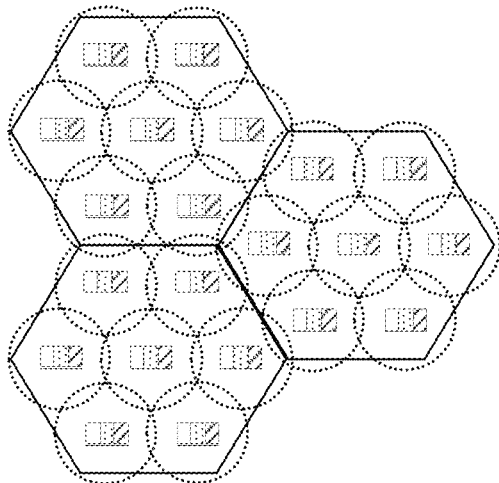
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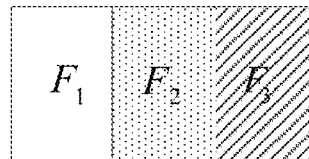
(a) DAS - Soft Frequency Reuses



(b) DAS - Hard Frequency Reuses



(c) DAS - Full Frequency Reuses

**FIG. 1**

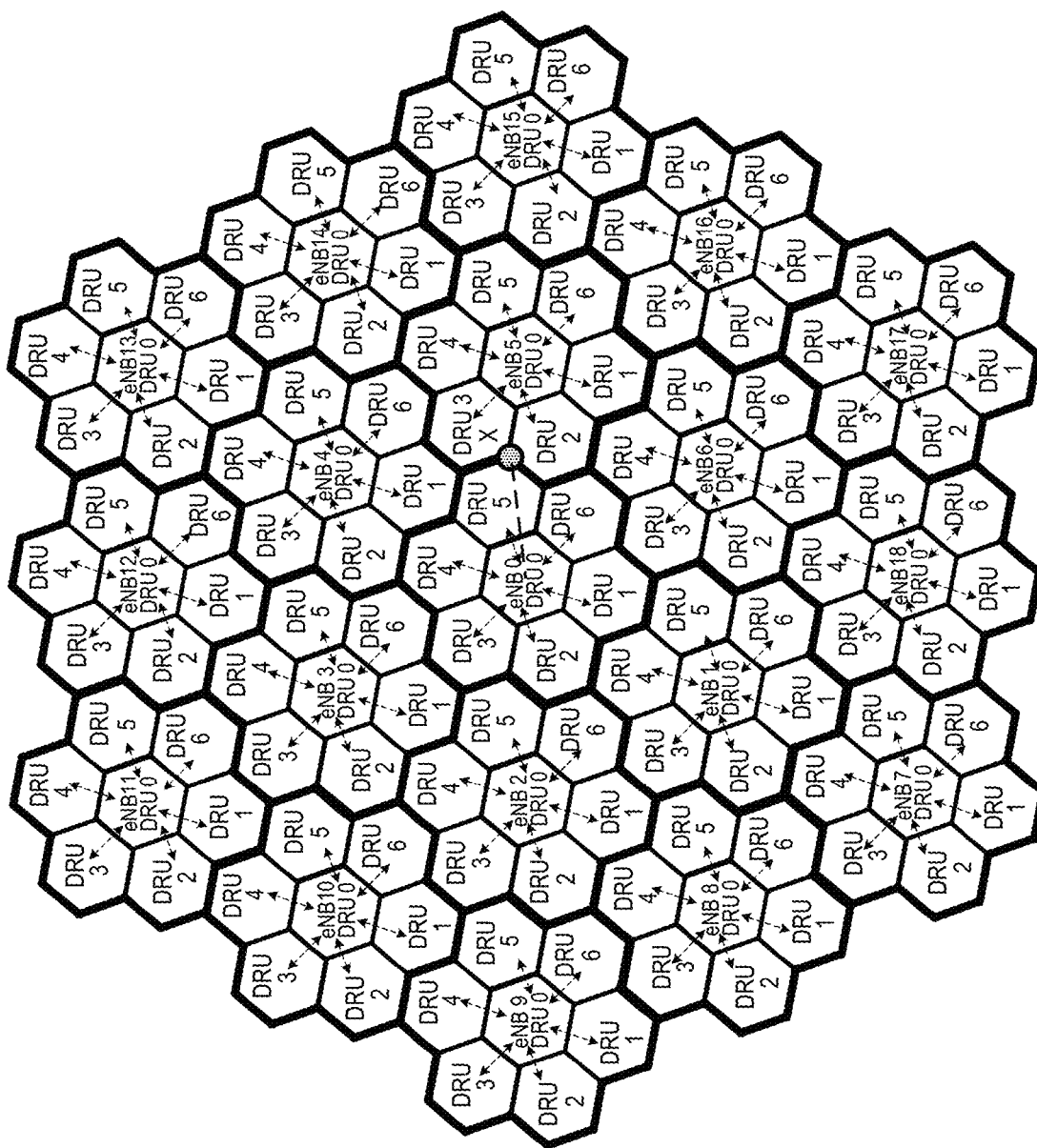


FIG. 2

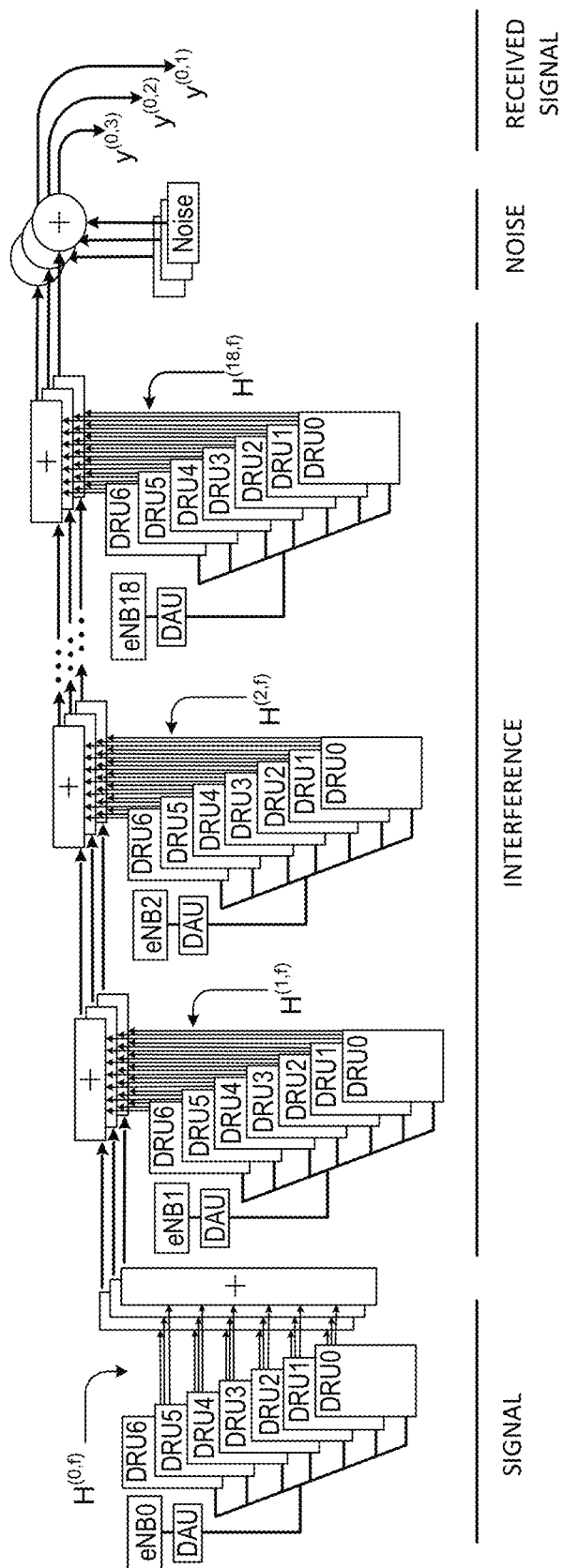


FIG. 3

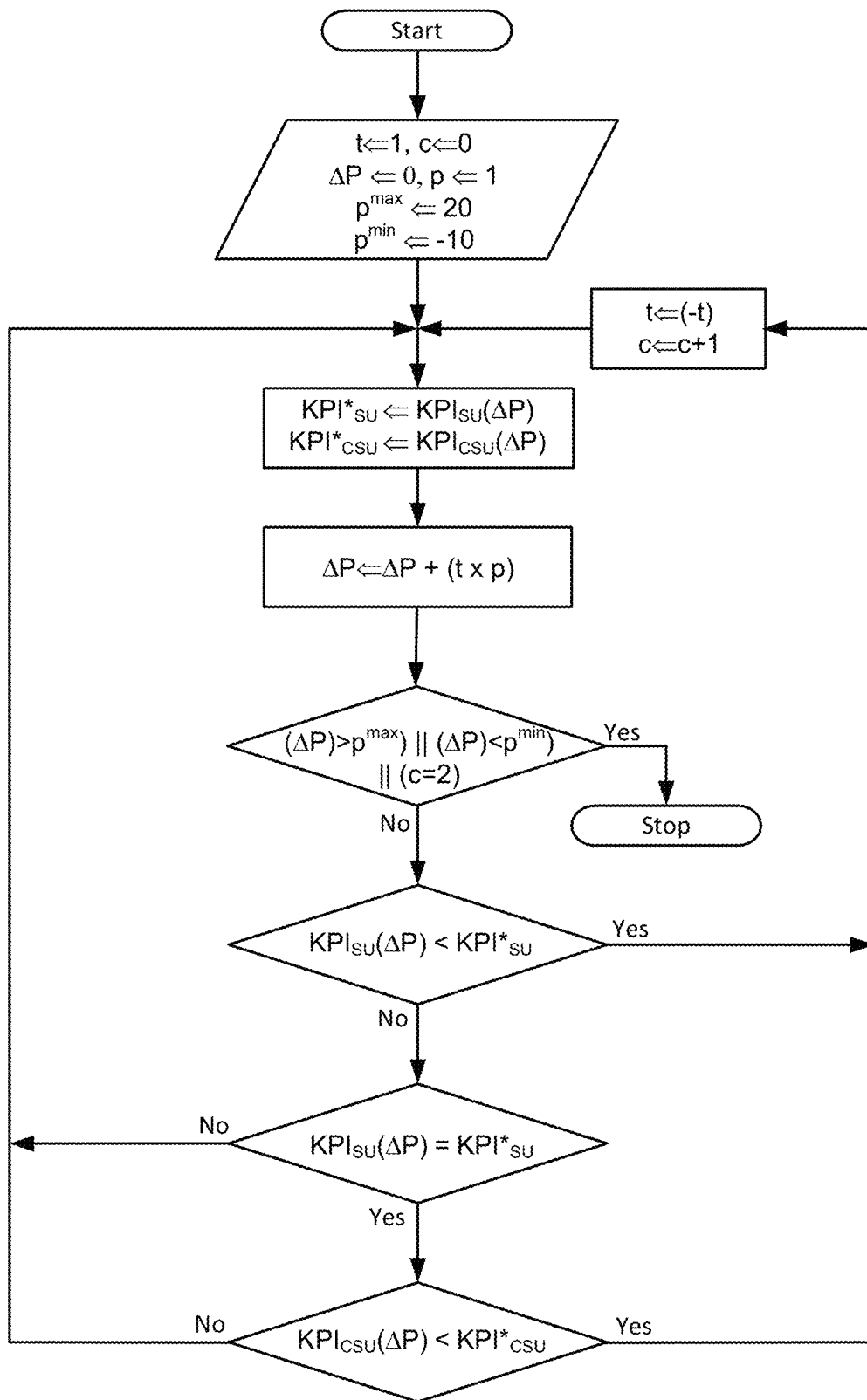


FIG. 4

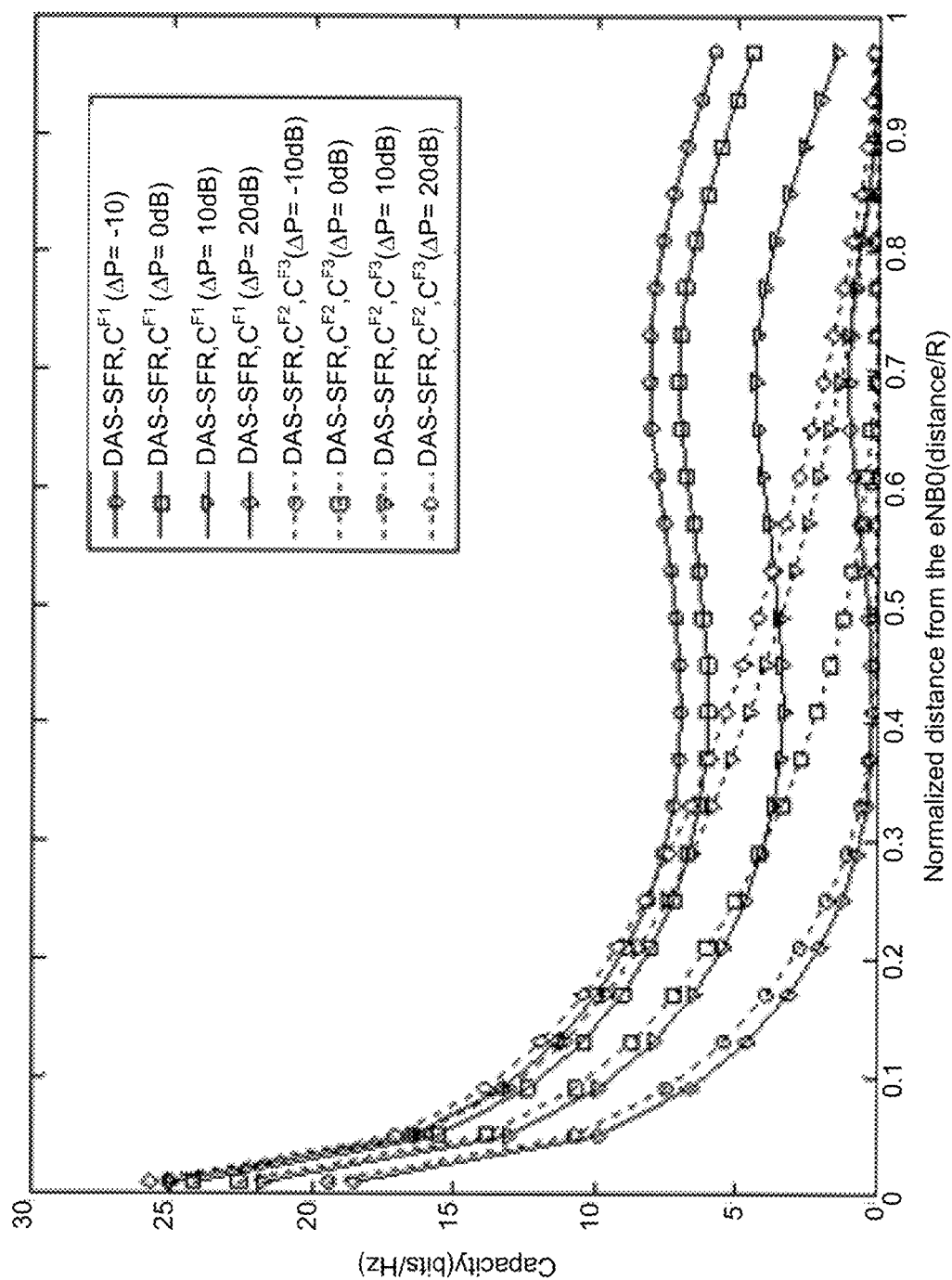


FIG. 5A

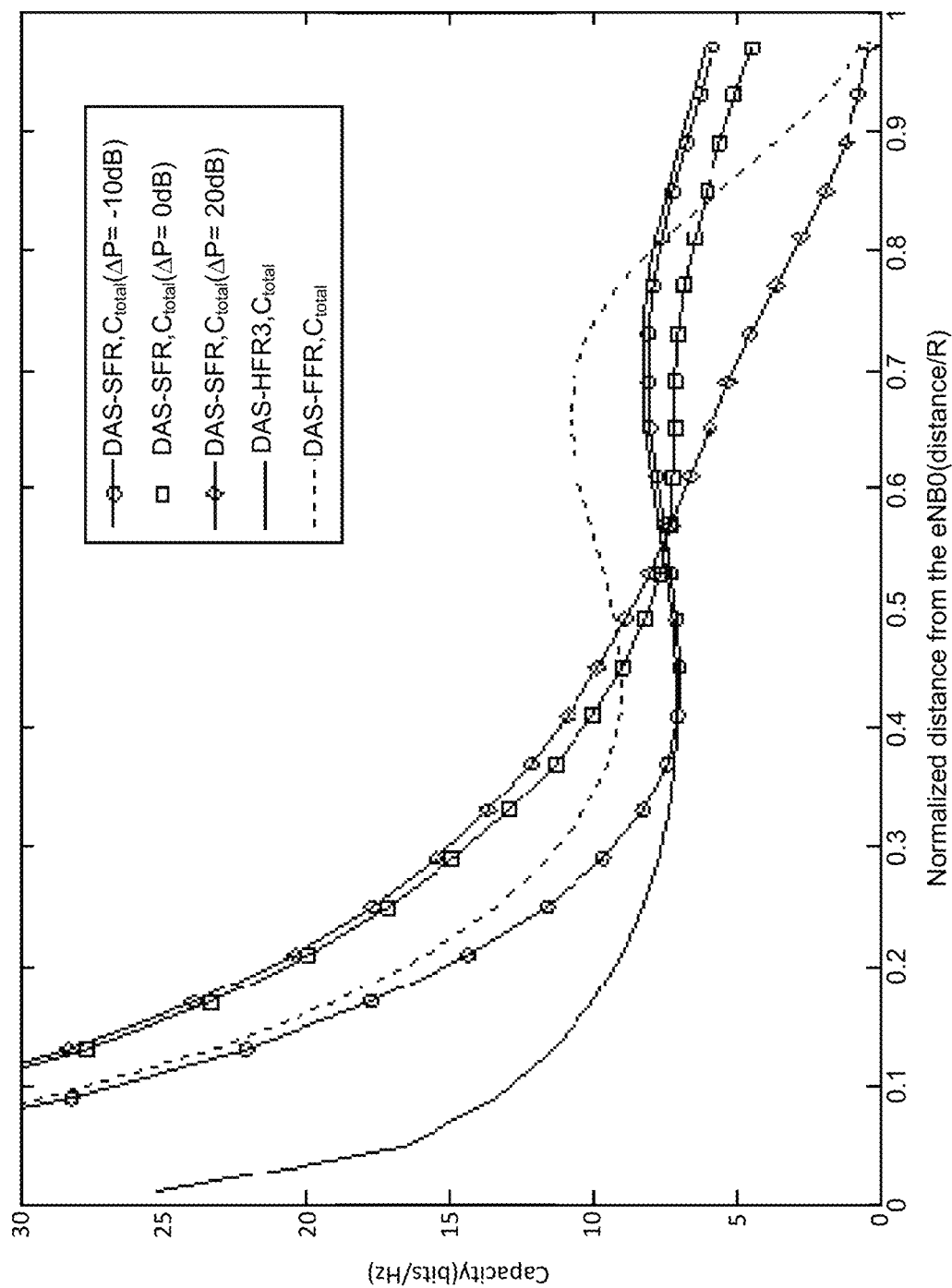


FIG. 5B

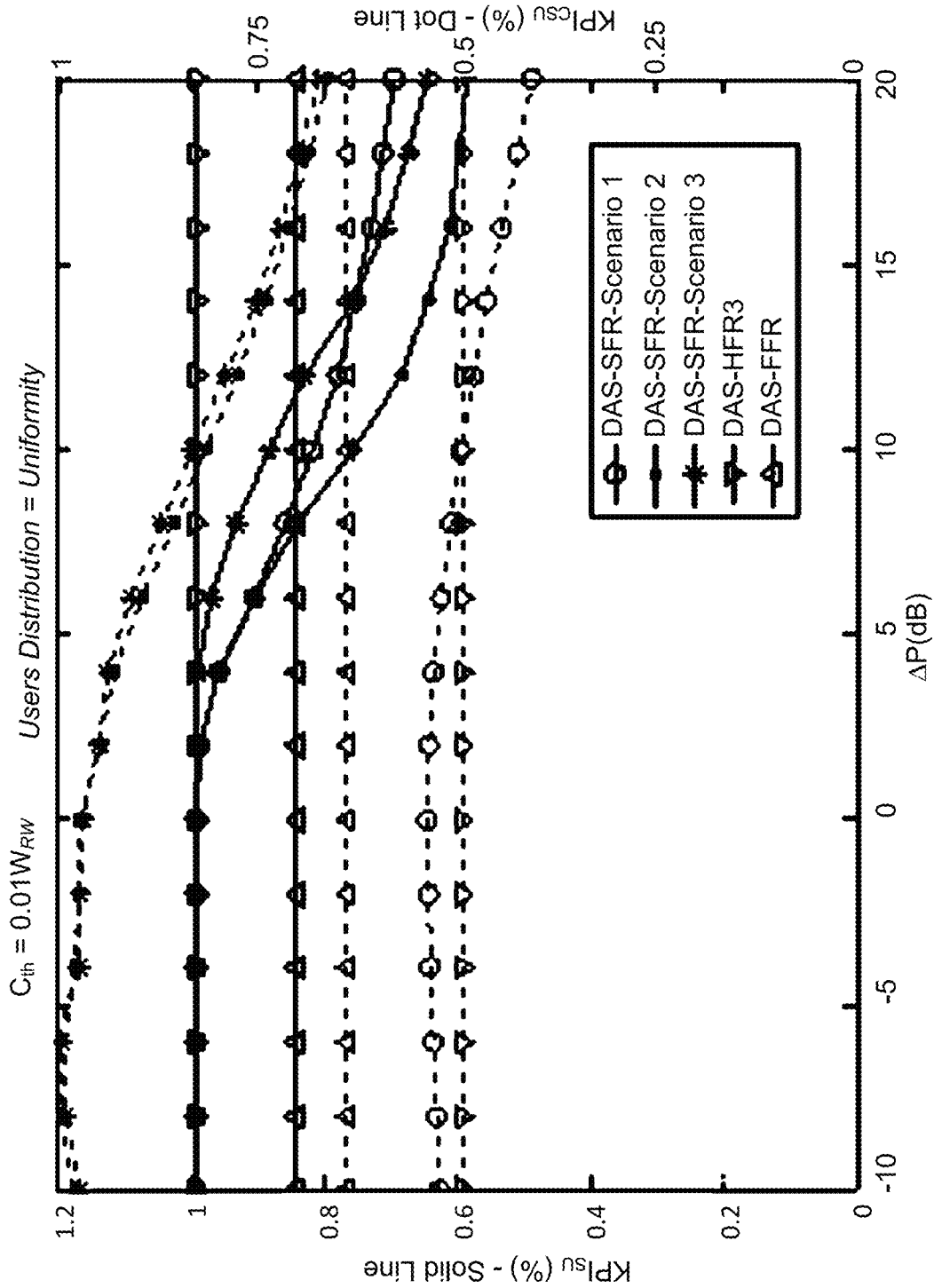
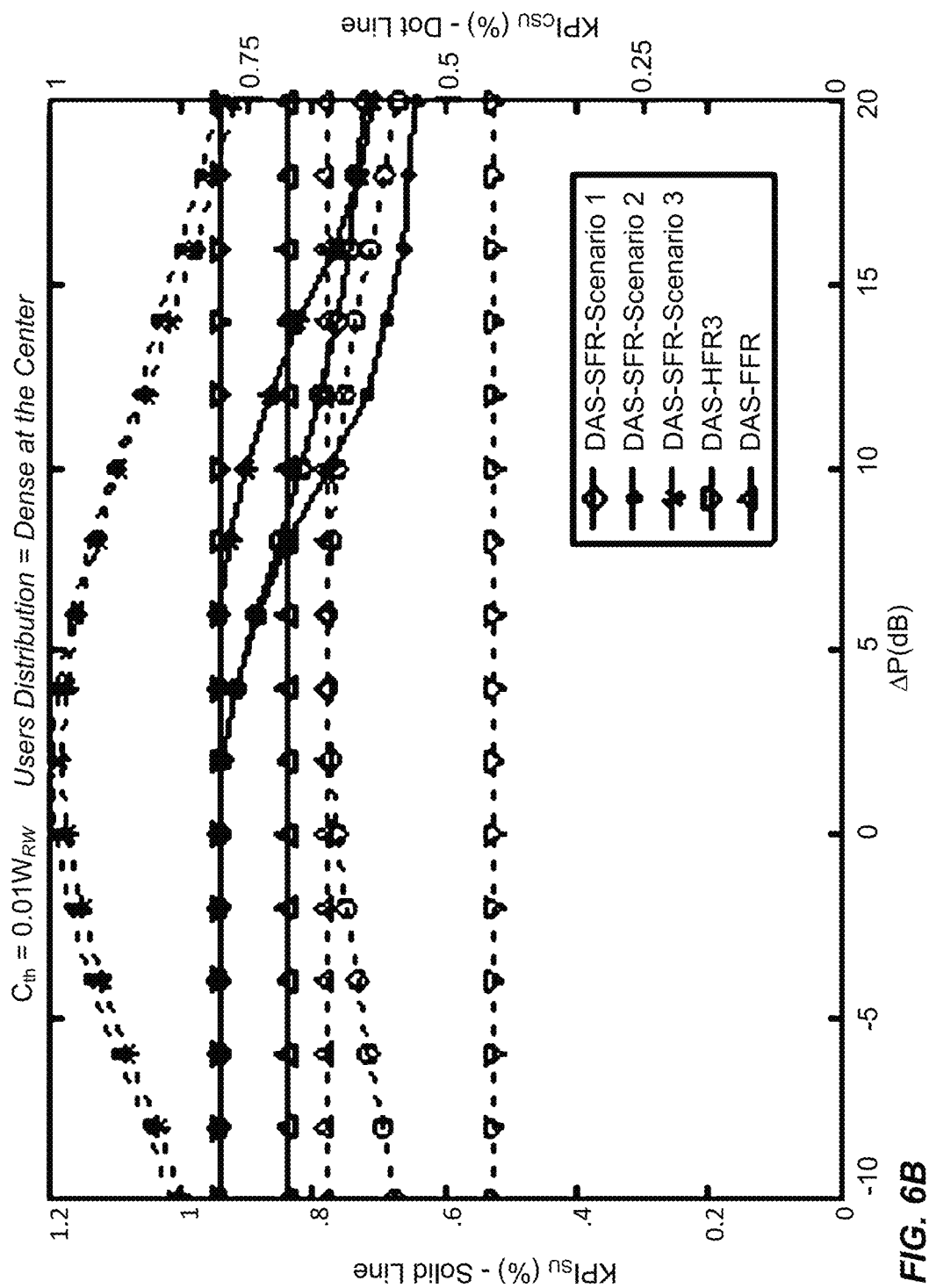


FIG. 6A



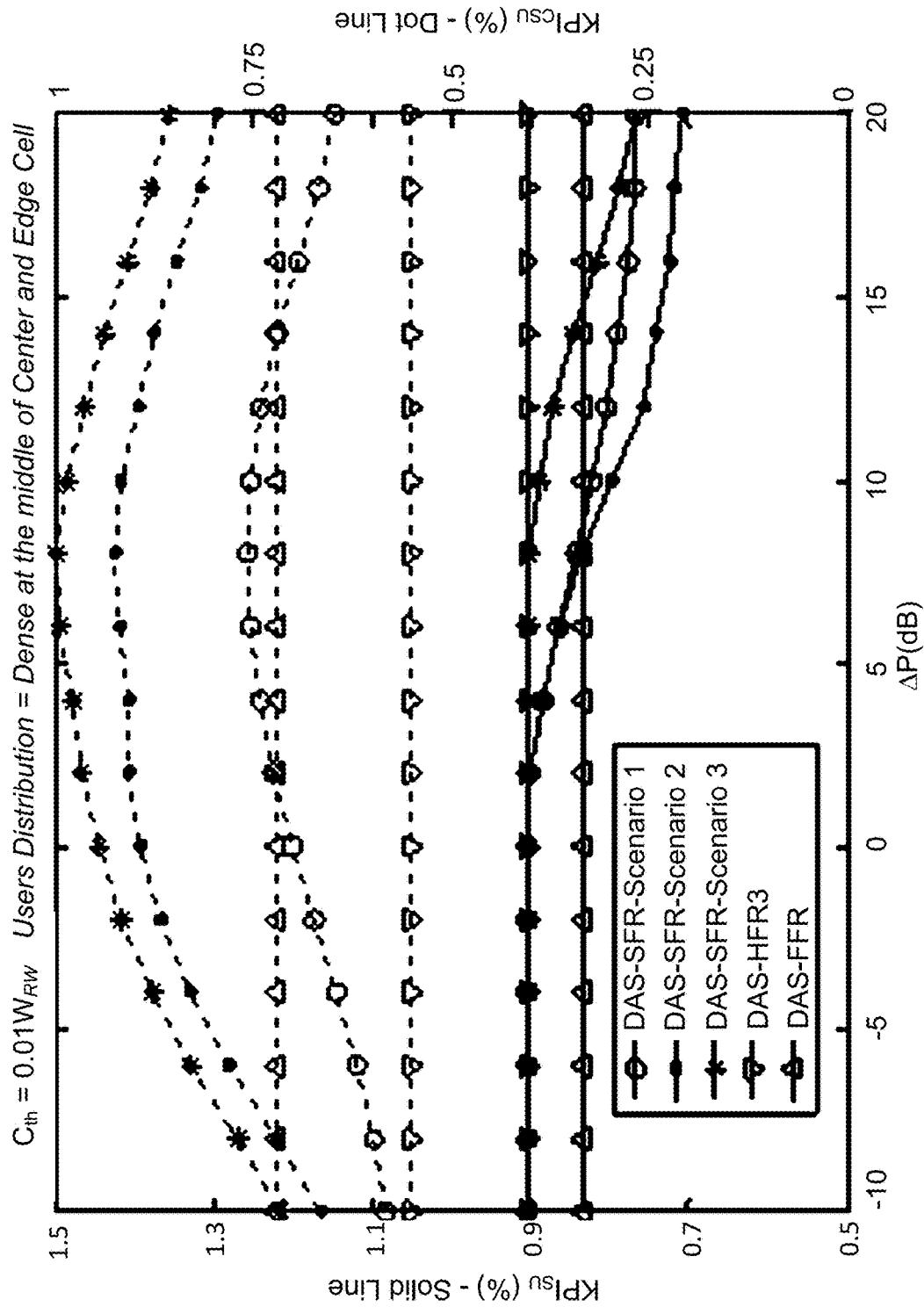


FIG. 6C

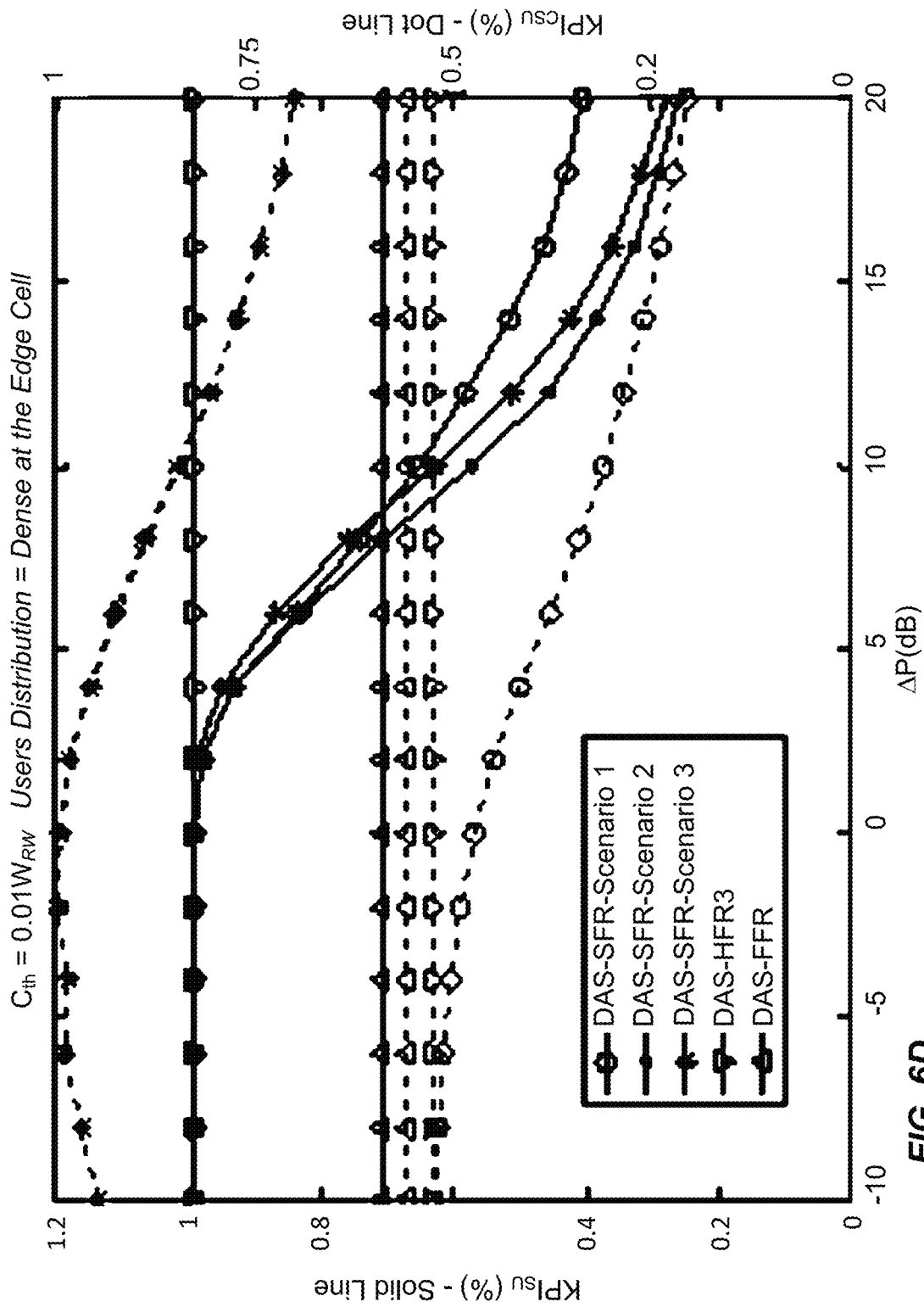


FIG. 6D

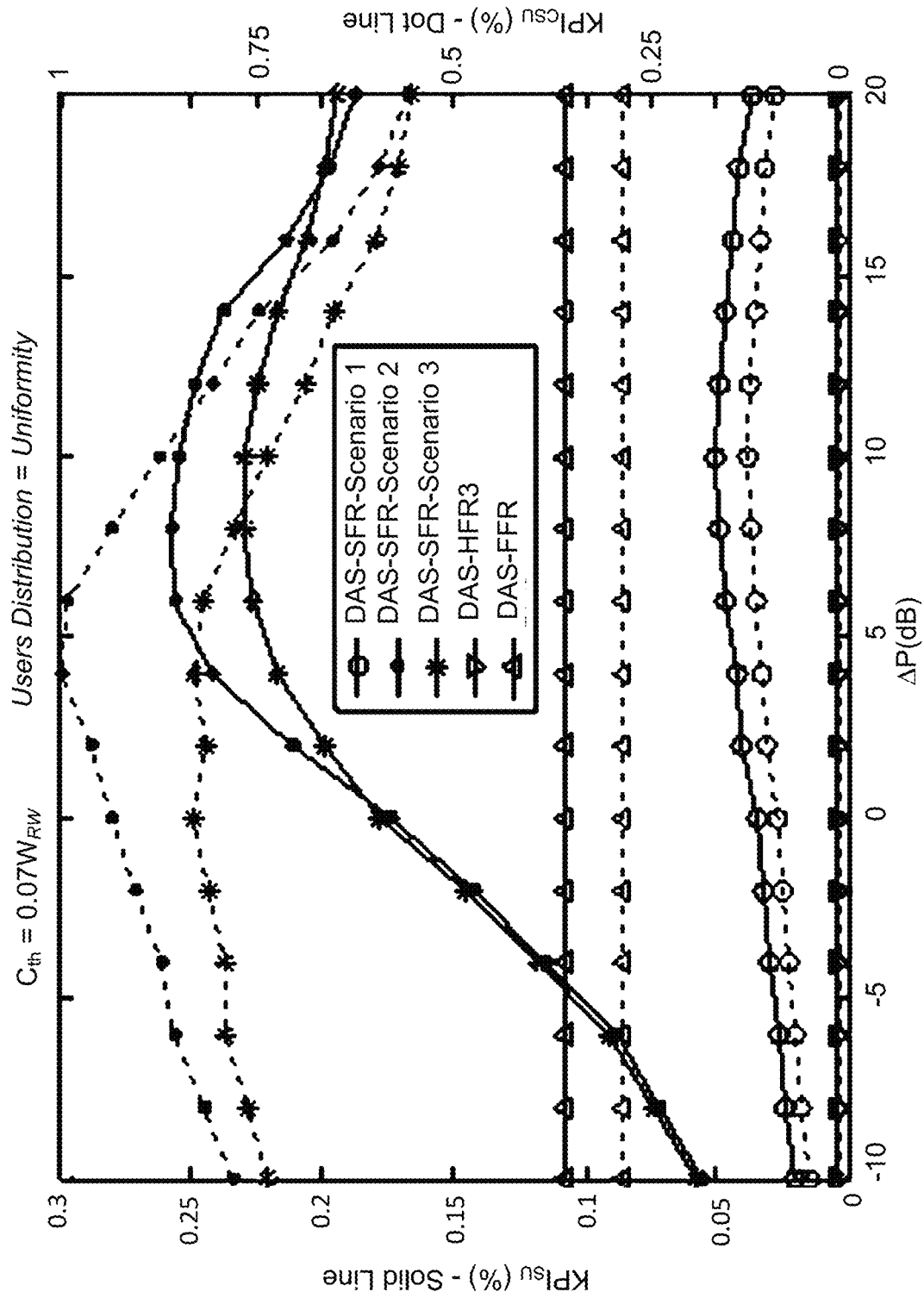


FIG. 7A

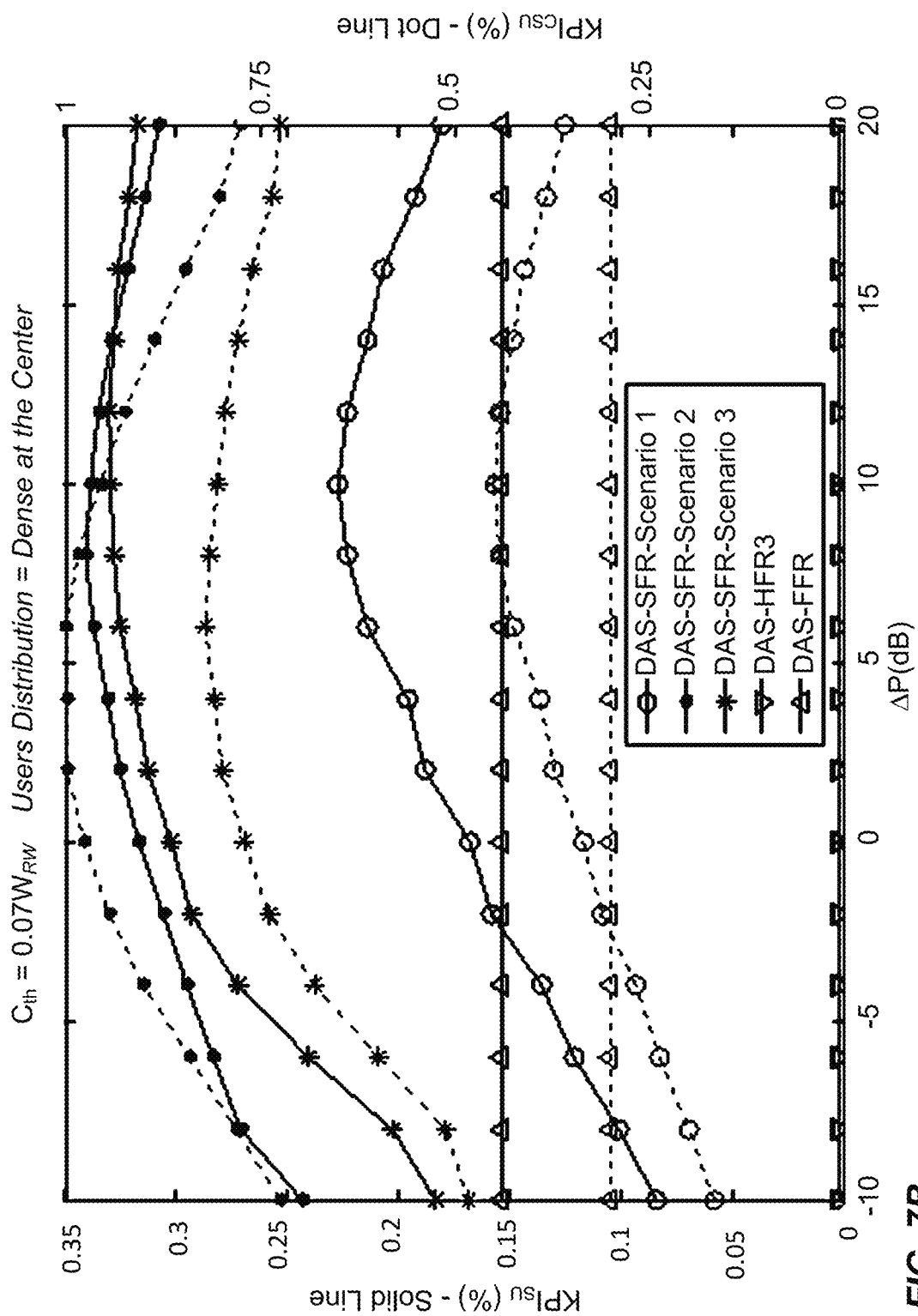


FIG. 7B

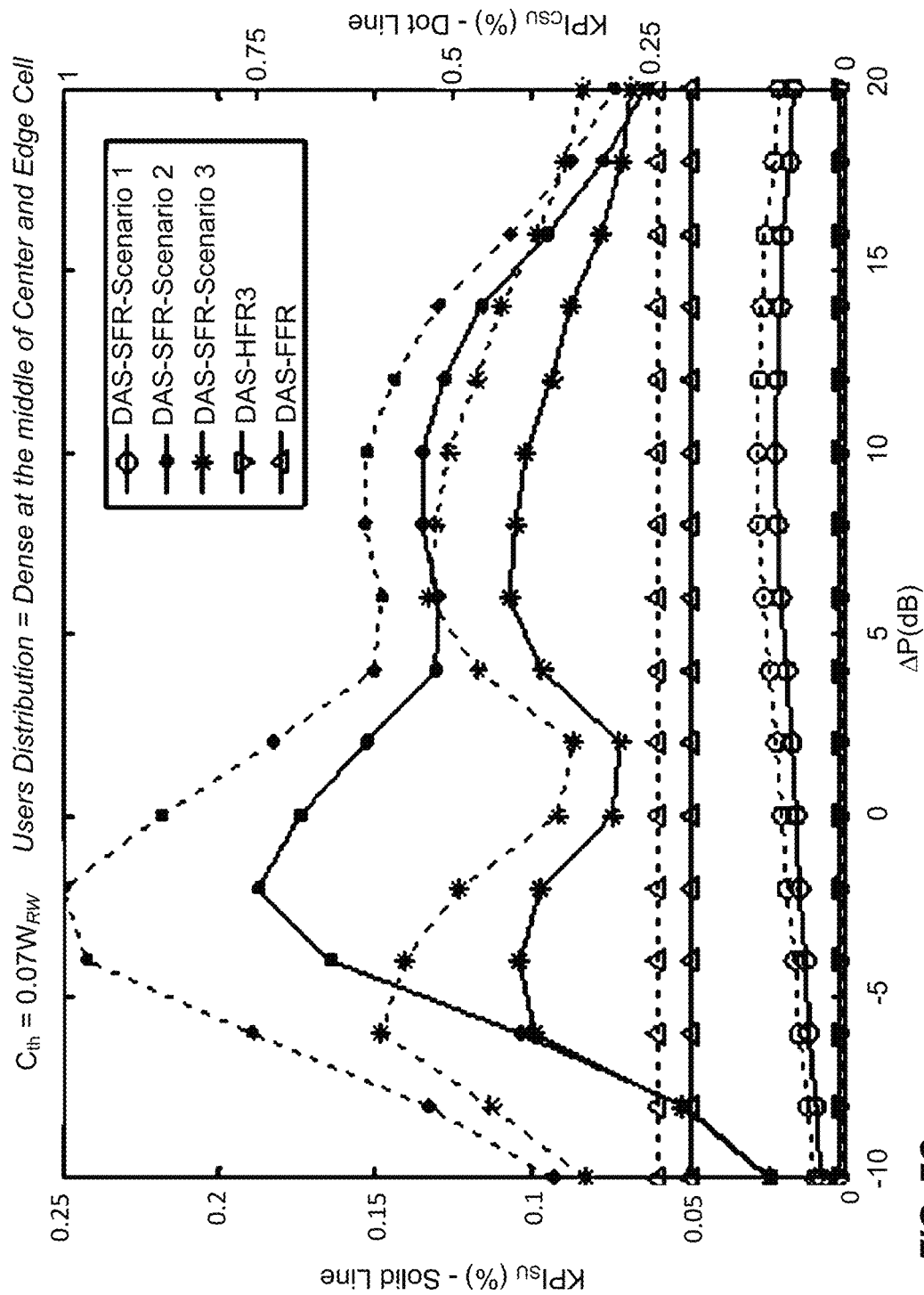


FIG. 7C

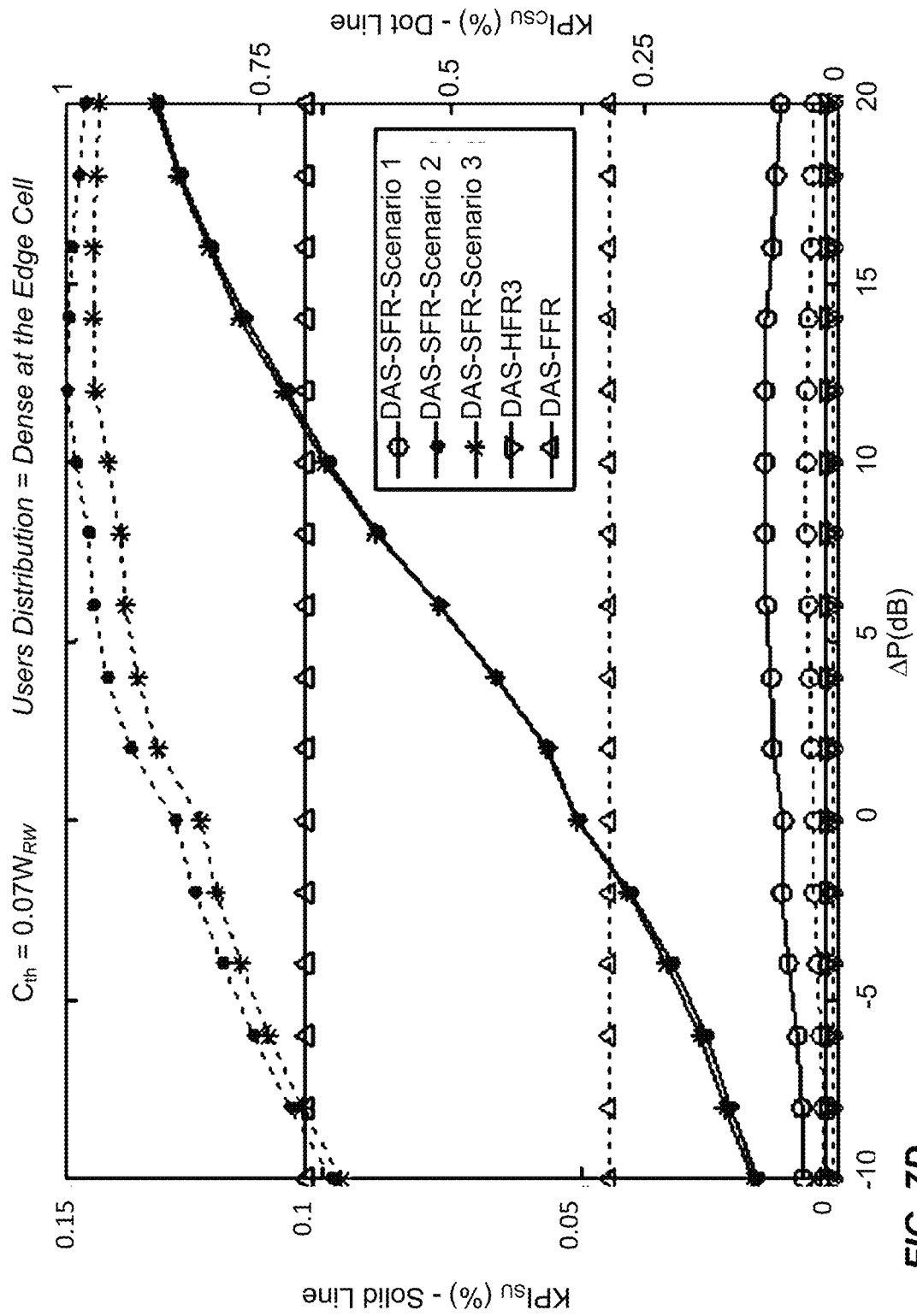


FIG. 7D

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SELF-OPTIMIZING DISTRIBUTED ANTENNA SYSTEM USING SOFT FREQUENCY REUSE

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 13/935,157, filed on Jul. 3, 2013, which claims priority to U.S. Provisional Patent Application No. 61/669,572, filed on Jul. 9, 2012, the disclosures of which are hereby incorporated by reference in their entirety.

SUMMARY OF THE INVENTION

According to an embodiment of the present invention, a method of determining a carrier power in a communications system including a processor is provided. The method includes a) setting a power differential between a reference carrier and one or more carriers, b) measuring a number of satisfied users at the power differential, and c) measuring a capacity for the satisfied users at the power differential, which may be referred to as an initial power differential. The method also includes d) adjusting the power differential by a predetermined amount and e) determining, using the processor, that the number of satisfied users at the adjusted power differential is greater than or equal to the number of satisfied users at the initial power differential. The method further includes f) repeating a)-e) and g) setting the carrier power at an iterated power level.

As described herein, unbalanced traffic distributions inside cellular networks are common occurrences. Embodiments of the present invention provide a throughput-balancing system that optimizes cellular performance according to the geographic traffic distribution in order to provide a high quality of service (QoS). The throughput of an Orthogonal Frequency Division Multiple Access (OFDMA) based architecture (DAS-SFR) that utilizes a combination Soft Frequency Reuse (SFR) technique and a Distributed Antenna System (DAS) is analyzed in light of embodiments of the present invention. A concept employed by this architecture is to distribute the antennas in a hexagonal cell in such a way that the central antenna is responsible for serving a special area, using all of the frequency bands, while the remaining antennas utilize only a subset of the frequency bands based on a frequency reuse factor. A DAS-SFR has the ability to distribute the cellular capacity (throughput) over a given geographic area. To enable throughput balancing among Distributed Antennas (DAs), embodiments of the present invention dynamically change the DA's carrier power to manage the inter-cell interference, as a function of the time-varying traffic. A Downlink Power Self-Optimization (PSO) algorithm, for three different resource allocation scenarios, is described for the DAS-SFR system. The transmit powers are optimized in order to maximize the spectral efficiency of a DAS-SFR and maximize the number of satisfied users under different user distributions in some embodiments. The PSO algorithm is able to guarantee a high Quality of Service (QoS) that concentrates on the number of satisfied users as well as the capacity of satisfied users as the two Key Performance Indicators (KPIs). Analytical derivations and simulations are discussed and used to evaluate the system performance for different traffic scenarios, and the results are presented.

Embodiments of the present invention provide a method and system for adjusting and potentially optimizing the powers of multiple carriers in a DAS-SFR system. By

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adjusting the power associated with the carriers provided by the central antenna of each cell, the SFR system enables higher system performance and an improved user experience as a result of higher system bandwidth.

Numerous benefits are achieved by way of the present invention over conventional techniques. For instance, embodiments of the present invention control the amount of resources allocated to users located in different areas, thereby increasing the frequency efficiency and also improving the data rate for cell edge users. As another example, embodiments of the present invention are useful in adjusting the powers of carriers to increase or maximize Key Performance Indicators, which are related to Quality of Service. These and other embodiments of the invention along with many of its advantages and features are described in more detail in conjunction with the text below and attached figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates band width allocation to antennas for three different combinations of DAS with SFR, HFR and FFR according to embodiments of the present invention;

FIG. 2 illustrates the structure of a Distributed Antenna System according to an embodiment of the present invention;

FIG. 3 illustrates a block diagram of the Received Signals with Interference Signals and Noises according to an embodiment of the present invention;

FIG. 4 is a simplified flowchart illustrating the PSO algorithm according to an embodiment of the present invention;

FIGS. 5A-5B illustrate plots of ergodic capacity versus the normalized distance from the DRU0 according to embodiments of the present invention;

FIGS. 6A-6D illustrate KPIs versus the ΔP for different distribution users scheme where $C_m = 0.01 W_{RB}$ according to embodiments of the present invention; and

FIGS. 7A-7D illustrate KPIs versus the ΔP for different distribution users scheme where $C_m = 0.07 W_{RB}$ according to embodiments of the present invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

In existing networks, parameters are manually adjusted to obtain a high level of network operational performance. 3GPP LTE is the preferred candidate for the next generation wireless networks. In the last 15 years, there has been substantial growth in cellular mobile communication systems. It is imperative to provide a high quality of service (QoS) at a minimum cost. With the substantial increase in cellular users, unbalanced throughput distributions are common in wireless networks which decrease the number of satisfied users. As traffic environments change, the network performance will not be optimum. Therefore, it is necessary to perform inter-cell optimization of the network dynamically according to the traffic environment, especially when cell traffic is not uniformly distributed. This is one of the important optimization issues in self-organizing networks (SON) for 3GPP LTE.

In SON, parameter tuning is done automatically based on measurements. The use of throughput-balancing is meant to deliver extra gain in terms of network performance. For throughput-balancing this is achieved by adjusting the network control parameters in such a way that ultra-high throughput users can offload to ultra-low throughput users

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inside the cell. In a live network, high throughput fluctuations occur. A SON enabled network, where the proposed SON algorithm monitors the network and reacts to these changes in throughput, can achieve better performance by distributing the throughput among users.

When the traffic loads among cells are not balanced, the satisfaction probability of heavily loaded cells may be lower, since their neighboring cells cause high inter-cell interference on cell edge users. In this case, throughput balancing can be conducted to alleviate and even avoid this problem.

Inter-cell interference, experienced by cell-edge users, is very high when this interference is a result of using the same subcarriers in the adjacent cell in the same time slot. High inter-cell interference means severe degradation of the cell-edge throughput since Mobile 3GPP LTE adopts a frequency reuse factor of one which is called Full Frequency Reuse (FFR), in which each cell serves users using the entire system bandwidth.

To mitigate the inter-cell interference in cellular systems, several techniques have been incorporated in these standards. Advanced receiver techniques such as Maximum Likelihood (ML) Multiuser Detection (MUD), the MMSE Receiver MUD and Other-cell interference cancellation are the three potential ways to reduce interference in cellular systems; however, these require a more complicated receiver. Advanced transmitter techniques such as Cooperative Encoding (CA), Closed-Loop MIMO Diversity Schemes (CLMD) and Beam forming are three other techniques to overcome the interference problem in cellular systems but CA requires very accurate channel state knowledge and real time inter-cell coordination, CLMD and Beam forming sacrifice spatial dimensions and require channel state knowledge.

One possible strategy to alleviate interference, both in the uplink and the downlink of cellular networks, is to reduce the overall transmit power by using a Distributed Antenna Systems (DAS), which also has the additional advantage of improving capacity and coverage.

The other possible strategy is a Soft Frequency Reuse technique; this technique effectively reduces the inter-cell interference by geographically spacing the competing transmissions farther apart, which benefits users near the cell boundaries.

A. Distributed Antenna System (DAS):

Distributed antenna systems (DAS) have been widely implemented in state-of-the art cellular communication systems to cover dead spots in wireless communications systems.

A DAS breaks the traditional radio base station architecture into two pieces: a central processing facility and a set of distributed antenna (DA), connected to the central facility by a high-bandwidth network. The DAS network transports radio signals, in either analog or digital form, to/from the central facility where all the base station's processing is performed. By replacing a single high-power antenna with several low-power antennas, distributed to give the same coverage as the single antenna, a DAS is able to provide more-reliable wireless services within a geographic area or structure while reducing its power consumption.

DAS has the following potential advantages such as: throughput improvement, coverage improvement, increased cellphone battery life and a reduction in transmitter power. Recent research has shown the benefits of using DAS in a cellular system for extending coverage, reducing call blocking rate and reducing inter-cell interference. An extension to a traditional DAS system is an Intelligent DAS, wherein

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each remote has the added flexibility of independently transmitting preselected carriers.

Most of the research on DAS has focused on investigating SINR advantages of DAS and analyzing its performance. Some research on DAS has focused on the analysis of the uplink performance due to its analytical simplicity, while there are few studies on the downlink performance of DAS, although the demand for high-speed data rate will be dominant in the downlink path. There is also very little research that considers the advantages of DAS in a multi-cell context.

B. Soft Frequency Reuse (SFR) Technique:

SFR has been proposed as an inter-cell interference mitigation technique in OFDMA based wireless networks. In SFR, the frequency band is divided into a fixed number of sub-bands; all sub-bands are used by all eNBs to serve "near" users; the other sub-bands are dedicated to "far" users. All sub-bands are allocated to the cells according to some predefined reuse factor. The SFR assigns sub-bands limited amount of transmit power to reduce inter-cell interference. The transmit power needs to be reduced enough to provide the required throughput to cell edge users of neighboring cells. Also, the sub-bands of reduced transmit power are used for the inner cell users.

Hard Frequency Reuse (HFR) suffers from a reduced spectral efficiency in such a way that, in HFR, the frequency band is divided into a fixed number of sub-bands that are allocated to the cells according to some predefined reuse factor and lets neighboring cells transmit on different sub-bands. On the other hand, SFR has the benefit of a full spectral efficiency and is a strong mechanism for inter-cell interference mitigation.

The capacity of the SFR was evaluated in assuming the offset in the transmit powers of different sub-bands. Self-organization of the transmit power in the uncoordinated systems was illustrated in where some transient time is required to converge on the equilibrium state of power allocation. Recent research on SFR has focused on optimal system design utilizing advanced techniques such as graph theory and convex optimization to maximize network throughput. Additional work on FFR and SFR consider alternative schedulers and the authors determined the frequency partitions in a two-stage heuristic approach.

Accordingly, this paper proposes a new architecture to suppress inter-cell interference. The proposed architecture combines DAS and SFR for an OFDMA system (e.g. LTE). We analyze the potential gains of DAS-SFR in a multi-cell environment.

The proposed architecture divides the entire spectral bandwidth F into 3 parts (F_1, F_2, F_3). The system assigns the eNB the full-reused frequency (all 3 parts) to the central antenna and the other 6 edge antennas work only on 1 part based on a reuse factor of Δ (ie. $\Delta=3$) in such a way that neighbor cell edge antennas do not use the same frequency, FIG. 1 (a). Two other combinations of DAS with HFR and FFR are also demonstrated in FIG. 1 (b) and FIG. 1 (c), respectively.

In order to attain user satisfaction, a minimum throughput should be provided for all users. In this publication, the system QoS is a function of the number of satisfied users. For a DAS-SFR architecture, the cell-edge throughput can be improved due to the reduced inter-cell interference as well as from the boosted cell-center transmission power. However, as compared to FFR the overall network throughput decreases at the same time, since the improvement is obtained at the cost of the cell-center user throughput. Thus, an efficient resource allocation and power allocation scheme

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is required to achieve the optimum overall network throughput in the DAS-SFR implementation.

Therefore, to improve the throughput for the cell edge users and further increase the number of satisfied users (the users that can achieve a targeted service bitrate), a downlink Power Self-Optimization (PSO) algorithm for three different resource allocation scenarios is proposed for the DAS-SFR. The transmit powers are allocated so that the spectral efficiency is maximized for the DAS-SFR, and the number of satisfied users is also maximized. The spectral efficiency represented by the ergodic capacity is obtained for the different scenarios. The results show that a DAS-SFR architecture effectively addresses inter-cell interference in a multi-cell environment, especially at the cell boundaries when compared to a HFR cellular architecture. The results also show that a DAS-SFR architecture achieves a non-trivial capacity enhancement over a HFR cellular architecture for a frequency reuse factor of 3.

A contribution of this work is the development of an analytical framework to evaluate the ergodic capacity of a DAS-SFR architecture. This is an important metric to consider, especially for users at the cell-edge since modern cellular networks are increasingly required to provide users with high data-rate and a guaranteed quality-of-service (QoS). This work presents a strategy for optimally allocating frequency RBs to edge users in a DAS-SFR architecture, based on a chosen performance threshold, which we define as T_p .

A system model is presented in section II. In section III, the achievable capacity is derived for a distributed antenna system. Formulation of the Power allocation algorithm is discussed in section IV. Analytical and simulation results are shown in section V and a conclusion is provided in section VI.

II. System Model

A. System Architecture:

The general architecture of an intelligent DAS in a multi-cell environment is shown in FIG. 2, where 7 Digital Remote Units (DRU) are connected to an eNB via an optical fiber and a Digital Access Unit (DAU). The DAUs are interconnected and connected to multiple sectors. This capability enables the virtualization of the eNB resources at the independent DRUs. The eNBs are linked to a public switched telephone network or a mobile switching center. DRUs are sectorized in such a way that each DRU allocated to a given eNB sector can be simulcast. For the simulcasting operation, the access network between each eNB and its DRUs should have a multi-drop bus topology. In contrast, the same area (7 DRUs) is covered by a single high-power eNB in a traditional cellular system.

The total transmit power of the n -th DRU of i -th cell in f -th frequency part is denoted $P_n^{(i,f)}$, where the central DRU of each cell is index by $n=0$.

We also consider the 2-tier cellular structure, where two continuous tiers of eighteen cells surround a given cell. Although this assumption of only 2-tiers of interfering cells is optimistic, a pessimistic assumption that all the DRUs and the eNB are transmitting full power all the time easily compensates.

B. Resource Allocation Scenarios:

In a multiuser DAS-SFR system, different users are located at varying distances from the DRUs and have varying channel conditions on the subcarriers. Therefore, resource allocation allows for efficient exploitation of multiuser diversity in the system.

Much of the research on SFR system design has focused on how to determine the size of the frequency partitions, for

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example, in a typical LTE system with a bandwidth of 5 MHz, 25 RBs may be available to serve users for each frequency part (F_i , $i=1, 2, 3$).

For a typical central cell, we can assume that the center DRU is assigned to the full-reused frequency and the other six edge DRUs are assigned to F_1 . Now, we consider three resource allocation scenarios:

Scenario 1: F_1, F_2, F_3 RBs are assigned to all users in the cell. Note that in this scenario, the very low SINR exterior users are inefficiently using the F_2 and F_3 RBs.

Scenario 2: F_1 RBs are assigned to all users but F_2 and F_3 RBs are solely assigned to interior users. Note that in this scenario, the available RBs are fully assigned to the interior users, which leads to a big gap between the numbers of allocated RBs to the interior users as compared to the exterior users.

Scenario3: F_1 RBs are solely assigned to the exterior users, whereas the F_2 and F_3 RBs are assigned to the interior users. In this scenario, all RBs are more fairly assigned between all users, as compared to the previously mentioned scenario. Moreover, in this scenario the RBs are allocated to the users following a SINR-based approach, in which the edge users using the F_1 RBs, and the interior users using the F_2 and F_3 RBs have a high SINR.

We primarily assume a single user scenario, and further extend it to a uniformly distributed multiuser LTE system. In a multiuser scenario, we investigate both the analytical and the simulation results in order to verify the system's capacity improvement.

Received Signal and Channel Model

The downlink path of a DAS can be considered as an equivalent MIMO system with additive interference and noise (FIG. 3). The received signal vector of the user in the central cell at frequency f can be expressed as,

$$y^{(0,f)} = \text{signal} + \text{interference} + \text{noise} \quad (1)$$

$$= H^{(0,f)} x^{(0,f)} + \sum_{i=1}^{18} H^{(i,f)} x^{(i,f)} + n^{(f)}$$

where $H^{(i,f)} \in \mathbb{C}^{1 \times 7}$, $i=0,1,\dots,18$, denotes the channel matrix between the DRUs in the i -th cell and the user in the central cell, $x^{(i,f)} = [x_0^{(i,f)}, x_1^{(i,f)}, \dots, x_6^{(i,f)}]^T \in \mathbb{C}^{7 \times 1}$, $i=0,1,\dots,18$ is the transmitted signal vector of the DRUs in the i -th cell, $n^{(f)} \in \mathbb{C}^{1 \times 1}$ denotes the white noise vector with distribution $\mathcal{CN}(0, \sigma_n^2 I_1)$. The distributed antenna power constraint is considered, we have

$$E[|x_n^{(i,f)}|^2] \leq P_n^{(i,f)}, n=0,1,\dots,6, i=0,1,\dots,18, \quad (2)$$

where in DAS-SFR,

$x_n^{(i,F_1)}=0, P_n^{(i,F_1)}=0$ when ($n=1,2,\dots,6$ and $i=1,2,\dots,7, 9, 11, 13, 15, 17$),

$x_n^{(i,F_2)}=0, P_n^{(i,F_2)}=0$ when ($n=1,2,\dots,6$ and $i=0,2,4,6,7, 8, 10, 11, 12, 14, 15, 16, 18$),

$x_n^{(i,F_3)}=0, P_n^{(i,F_3)}=0$ when ($n=1,2,\dots,6$ and $i=0,1,3,5,8, 9, 10, 12, 13, 14, 16, 17, 18$),

in DAS-HFR3 (frequency reuse factor 3),

$x_n^{(i,F_1)}=0, P_n^{(i,F_1)}=0$ when ($n=1,2,\dots,6$ and $i=1,2,\dots, 7, 9, 11, 13, 15, 17$),

$x_n^{(i,F_2)}=0, P_n^{(i,F_2)}=0$ when ($n=1,2,\dots,6$ and $i=0,2,4,6, 7, 8, 10, 11, 12, 14, 15, 16, 18$),

$x_n^{(i,F_3)}=0, P_n^{(i,F_3)}=0$ when ($n=1,2,\dots,6$ and $i=0,1,3,5, 8, 9, 10, 12, 13, 14, 16, 17, 18$),

in DAS-FFR,

$x_n^{(i,f)} \neq 0, P_n^{(i,f)} \neq 0$ when ($n=0,1,\dots,6$ and $i=0,1,\dots,18, f=F_1, F_2, F_3$),

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where $P_n^{(i,f)}$ denotes the power constraint of the n-th DRU in the i-th cell for frequency band f.

The composite fading channel matrix $H^{(i,f)}$, $i=0,1,\dots,18$, encompasses not only small-scale fading (fast fading) but also large-scale fading (slow fading), which is modeled as

$$H^{(i,f)} = H_w^{(i,f)} L^{(i,f)} \quad (3)$$

$$= [h_0^{(i,f)}, h_1^{(i,f)}, \dots, h_6^{(i,f)}] \cdot \text{diag}\{l_0^{(i,f)}, l_1^{(i,f)}, \dots, l_6^{(i,f)}\}$$

where, $H_w^{(i,f)}$ and $L^{(i,f)}$ reflect the small-scale channel fading and the large-scale channel fading between the DRUs in the i-th cell and the user in the central cell, respectively. $\{h_j^{(i,f)} | j=0,1,\dots,6; i=0,1,\dots,18; f=F_1, F_2, F_3\}$ are independent and identically distributed (i.i.d) circularly symmetric complex Gaussian variables with zero mean and unit variance, and $\{l_j^{(i,f)} | j=0,1,\dots,6; i=0,1,\dots,18; f=F_1, F_2, F_3\}$ can be modeled as

$$l_n^{(i,f)} = \sqrt{[D_n^{(i)}]^{-\gamma} \chi_n^{(i,f)}}, n=0,1,\dots,6, i=0,1,\dots,18 \quad (4)$$

Where $D_n^{(i)}$ and $\chi_n^{(i,f)}$ are independent random variables representing the distance and the shadowing between the user in the central cell and the n-th DRU in the i-th cell, respectively. γ denotes the path loss exponent. $\{\chi_j^{(i,f)} | j=0,1,\dots,6; i=0,1,\dots,18; f=F_1, F_2, F_3\}$ are i.i.d random variables with probability density function (PDF)

$$f_\chi(\chi) = \frac{1}{\sqrt{2\pi} \lambda \sigma_\chi \chi} \exp\left(-\frac{(\ln \chi)^2}{2\lambda^2 \sigma_\chi^2}\right), \chi > 0, \quad (5)$$

Where σ_χ is the shadowing standard deviation and

$$\lambda = \frac{\ln 10}{10}.$$

Since the number of interfering sources is sufficiently large and interfering sources are independent with each other, the interference plus noise is assumed to be a complex Gaussian random vector as follows:

$$N^{(f)} = \sum_{i=1}^{18} H^{(i,f)} X^{(i,f)} + n^{(f)} \quad (6)$$

The variance of N is derived by Central Limit Theorem as

$$\text{Var}(N^{(f)}) = \left[\sum_{i=1}^{18} \sum_{n=0}^6 [l_n^{(i,f)}]^2 P_n^{(i,f)} + \sigma_{n^{(f)}}^2 \right] I_1 \quad (7)$$

$$= [\sigma^{(f)}]^2 I_1$$

Therefore, the received signal at the mobile station at a given symbol duration is given by

$$y^{(0,f)} = H_w^{(0,f)} L^{(0,f)} x^{(0,f)} + N^{(f)} \quad (8)$$

Dynamic Power Allocation

In DAS-SFR, it is important to dynamically change the frequency bands power of each DRU to cope with a dynamically changing distribution of traffic and to balance the

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throughput in each cell. Thus, it is necessary to dynamically change the frequency bands power such that the maximum number of users in each cell could be satisfied (number of users that can achieve the targeted service bitrate). In this study we are interested in a proper power allocation which maximizes the number of satisfied users and their capacity. Without proper power allocation, there may be cases of unbalanced capacity (throughput) where a few users can have ultra-high throughput and most of the users have ultra-low throughput. In some cases, for the existence of very large interference, some users will be always unsatisfied. Therefore, a proper power allocation can increase the throughput of the rest of the users. However, the number of unsatisfied users' throughput will be decreased.

III. Achievable Capacity of Distributed Antenna System

If we assume that the channel state information is known only at the receiver (CSIR) and the channel is ergodic, the ergodic Shannon capacity at a given location of the target mobile station for the central cell can be calculated by

$$C^{(f)} = E_{H_w^{(0,f)}} \left[\log_2 \det \left(I_1 + \frac{1}{[\sigma^{(f)}]^2} (H_w^{(0,f)} L^{(0,f)} P^{(0,f)} (H_w^{(0,f)} L^{(0,f)})^H) \right) \right] \quad (9)$$

where $P^{(0,f)}$ is the covariance matrix of the transmitted vector x and given by $\text{diag}\{P_0^{(0,f)}, P_1^{(0,f)}, \dots, P_6^{(0,f)}\}$. If ergodicity of the channel is assumed, the ergodic capacity can be obtained as

$$C^{(f)} = E_{H_w^{(0,f)}} \left[\log_2 \left(1 + \frac{1}{[\sigma^{(f)}]^2} \sum_{i=0}^6 |h_i^{(0,f)}|^2 [l_i^{(0,f)}]^2 P_i^{(0,f)} \right) \right] \quad (10)$$

$$= \int_{\gamma_f=0}^{\infty} \log_2(1 + \gamma_f) f_{\gamma_f}(\gamma_f) d\gamma_f$$

where

$$\gamma_f = \frac{1}{[\sigma^{(f)}]^2} \sum_{i=0}^6 |h_i^{(0,f)}|^2 [l_i^{(0,f)}]^2 P_i^{(0,f)}$$

is a weighted chi-squared distributed random variable with p.d.f given by

$$f_{\gamma_f}(\gamma_f) = \sum_{i=0}^6 \frac{[\sigma^{(f)}]^2 \pi_i}{[l_i^{(0,f)}]^2 P_i^{(0,f)}} \exp\left(-\frac{[\sigma^{(f)}]^2 \gamma_f}{[l_i^{(0,f)}]^2 P_i^{(0,f)}}\right), \quad (11)$$

where

$$\pi_i = \prod_{k=0, k \neq i}^6 \frac{[l_i^{(0,f)}]^2 P_i^{(0,f)}}{[l_i^{(0,f)}]^2 P_i^{(0,f)} - [l_k^{(0,f)}]^2 P_k^{(0,f)}}.$$

Then the ergodic capacity for MISO vector channel can be obtained in a simple form by

$$\text{MISO: } C^{(f)} = -\frac{1}{\ln 2} \pi_i \exp\left(-\frac{[\sigma^{(f)}]^2}{[l_i^{(0,f)}]^2 P_i^{(0,f)}}\right) E\left(-\frac{[\sigma^{(f)}]^2}{[l_i^{(0,f)}]^2 P_i^{(0,f)}}\right), \quad (12)$$

$$f = F_1, F_2, F_3$$

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where, $Ei(t)$ is the exponential integral function

$$\left(Ei(t) = - \int_{-t}^{\infty} e^{-t} / t dt \right)$$

and can be easily calculated with popular numerical tools such as MATLAB and MAPLE. Since the derivation for this MISO vector channel is a generalization of a SISO channel, the ergodic capacity for SISO channel is given, respectively, by

$$SISO: C^{(f)} = - \frac{1}{\ln 2} \exp \left(- \frac{[\sigma^{(f)}]^2}{[\rho_0^{(0,f)}]^2 P_0^{(0,f)}} \right) Ei \left(- \frac{[\sigma^{(f)}]^2}{[\rho_0^{(0,f)}]^2 P_0^{(0,f)}} \right), \quad (13)$$

$$f = F_1, F_2, F_3$$

Hence, the total ergodic capacity of the system can be obtained by adding the capacity of the individual carriers,

$$C_{total} = C^{(F_1)} + C^{(F_2)} + C^{(F_3)} \quad (14)$$

where, for DAS-SFR at the central cell,

$$C^{(F_1)}: \text{MISO}, C^{(F_2)}: \text{SISO}, C^{(F_3)}: \text{SISO}$$

for DAS-HFR3 (frequency reuse factor 3) at the central cell,

$$C^{(F_1)}: \text{MISO}, C^{(F_2)}: \text{nothing}, C^{(F_3)}: \text{nothing}$$

for DAS-FFR at the central cell,

$$C^{(F_1)}: \text{MISO}, C^{(F_2)}: \text{MISO}, C^{(F_3)}: \text{MISO}$$

In the following section, we present the analytical and numerical results using a simulation to corroborate the theoretical analysis.

IV. Formulation of Power Allocation

In this section, we formulate the power allocation problem to maximize the number of satisfied users and also maximize the total satisfied users capacity.

For the problem formulation we consider a service area with nineteen cells shown in FIG. 2.

In a multiusers scenario, we can directly map the ergodic capacity of each user to what we obtained in section III depending on the position and the power. Therefore, having a number of resource blocks assigned to user k ($N_k^{RB(f)}$), the real throughput at user k can be written in terms of bps (bit per second) as follow,

$$C_k^{real}(P) = W_{RB} \sum_{i=1}^3 N_k^{RB(F_i)} \cdot C_k^{(F_i)}(P) \quad (15)$$

where, W_{RB} is the resource block bandwidth. $C_k^{(F_i)}(P)$ is the ergodic capacity of user k where $P = \{P_n^{(i,f)} | n=0,1, \dots, 6, i=0,1, \dots, 18, f=1, 2, 3\}$

We consider the following key performance indicators (KPIs) in the power allocation system:

1. KPI (Number of Satisfied Users): We can derive a metric defining a percent of satisfied users (i.e., users that can achieve the targeted service bit rate, for example, 1 Mbits/s). The percent of satisfied users (out of m users) would be,

$$KPI_{SU}(P) = \frac{\sum_{k=1}^m G_k(P)}{N_{user}^{total}} \quad (16)$$

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where N_{user}^{total} is total number of users and

$$G_k(P) = \begin{cases} 1 & \text{when } C_k^{real}(P) > C_{th} \\ 0 & \text{otherwise} \end{cases}$$

Using these equations, C_{th} is a threshold capacity (targeted service bit rate) and $G_k(P)$ is unity when the capacity for a user (indexed by k) exceeds the threshold capacity and is equal to zero when the capacity is less than or equal to the threshold capacity.

2. KPI_{CSU} (Capacity of Satisfied Users): The total capacity of satisfied users would be,

$$KPI_{CSU}(P) = \frac{\sum_{k \in SUS} C_k^{real}(P)}{(W_{(F_1)} + W_{(F_2)} + W_{(F_3)})/3} \quad (17)$$

where W_f is the bandwidth of frequency band f and $SUS = \{k | G_k = 1, k=1, 2, \dots, m\}$ is the satisfied users set.

If more than three carriers are utilized in a cell, the number of carriers and the divisor in the denominator will increase as appropriate.

Now, our QoS function is the weighted combination of the two KPIs (cost factors) which we have already introduced. Obviously our objective function is to maximize the QoS function.

$$\text{Maximize}_P QoS(P) = w_1 \cdot KPI_{SU}(P) + w_2 \cdot KPI_{CSU}(P) \quad (18)$$

We can further simplify the objective functions in Eq. 18 based on the following arguments:

Use round robin scheduling and equal bandwidth frequency for all frequency bands, therefore, we can rewrite the real capacity in Eq. 15 as,

$$C_k^{real}(P) = W_{RB} \sum_{i=1}^3 N_k^{RB(F_i)} \cdot C_k^{(F_i)}(P) \xrightarrow{\text{Round Robin}} \quad (19)$$

$$W_{RB} \sum_{i=1}^3 \frac{N_{RB}^{(F_i)}}{N_{user}^{(F_i)}} C_k^{(F_i)}(P) \xrightarrow{W_{RB} N_{RB}^{(F_i)} = W_{(F_i)}} \quad (20)$$

$$\sum_{i=1}^3 \frac{W_{(F_i)}}{N_{user}^{(F_i)}} C_k^{(F_i)}(P) \xrightarrow{W_{(F_1)} = W_{(F_2)} = W_{(F_3)} = W_F} W_F \sum_{i=1}^3 \frac{C_k^{(F_i)}(P)}{N_{user}^{(F_i)}} \quad (21)$$

Where $N_{user}^{(f)}$ is the number of users which can be supported by frequency band f .

Since it is not practical to calculate the ergodic capacity for the individual users, the aforementioned simplification is valid for the theoretical analysis and cannot be extended to practical applications. However, in practice, the number of the satisfied users and therefore the KPIs, are found based on the real users' throughput ($C_k^{real}(P)$) after the power allocation procedure.

Note that, the optimization problem variable (P) is $171=19 \times 9$, where the first term in the product is due to the fact that we have 19 cells, and the second term is because each cell of DAS-SFR has 9 changeable user frequency band powers. These 9 changeable user frequency band powers are

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comprised of 6 frequency band powers for the edge DRUs and 3 frequency band powers for central DRUs.

We decrease the optimization problem variable from 171 to 1 in such a way that only the central DRU's frequency bands power, which are not assigned to the edge DRUs, are perturbed. The central DRU's F_2 and F_3 power, which are not assigned to the edge DRUs, are perturbed for the central cell (eNB0) in a DAS-SFR configuration.

So the optimization problem is simplified to,

$$\text{Maximize}_{\Delta P} QoS(\Delta P) = w_1 \cdot KPI_{SU}(\Delta P) + w_2 \cdot KPI_{CSU}(\Delta P) \quad (20)$$

where in DAS-SFR,

$$\Delta P(\text{dB}) = P'(\text{dBm}) - P(\text{dBm})$$

$$P_n^{(i,f)} =$$

$$\begin{cases} P & \text{when } (n = 0, 1, \dots, 6 \text{ and } i = 0, 8, 10, 12, 14, 16, 18 \text{ and } f = F_1) \text{ or} \\ & (n = 0, 1, \dots, 6 \text{ and } i = 1, 3, 5, 9, 13, 17 \text{ and } f = F_2) \text{ or} \\ & (n = 0, 1, \dots, 6 \text{ and } i = 2, 4, 6, 7, 11, 15 \text{ and } f = F_3), \\ P' & \text{when } (n = 0 \text{ and } i = 1, 2, \dots, 7, 9, 11, 13, 15, 17 \text{ and } f = F_1) \text{ or} \\ & (n = 0 \text{ and } i = 0, 2, 4, 6, 7, 8, 10, 11, 12, 14, 15, 16, 18 \text{ and } f = F_2) \text{ or} \\ & (n = 0 \text{ and } i = 0, 1, 3, 5, 8, 9, 10, 12, 13, 14, 16, 17, 18 \text{ and } f = F_3), \\ 0 & \text{otherwise} \end{cases}$$

$$KPI_{SU}(\Delta P) = \frac{\sum_{k=1}^m G_k(\Delta P)}{N_{user}^{total}} \text{ where } G_k(\Delta P) = \begin{cases} 1 & \text{when } \sum_{i=1}^3 \frac{C_k^{(F_i)}(\Delta P)}{N_{user}^{(F_i)}} > \frac{C_{th}}{W_F}, \\ 0 & \text{otherwise} \end{cases}$$

$$KPI_{CSU}(\Delta P) = \sum_{k \in SU} \sum_{i=1}^3 \frac{C_k^{(F_i)}(\Delta P)}{N_{user}^{(F_i)}}$$

In our analysis, we assume that P is fixed and only P' changes in magnitude.

In multiuser systems, we need to consider the different resource allocation scenarios which were defined in section II. B

In LTE systems, eNB distinguishes between the interior and the exterior users based on their corresponding uplink power received at the central DRU. Particularly in DAS-SFR, since none of the DRUs except the central DRU operates in F_2 and F_3 it is possible to apply the above-mentioned method (distinguishing between the interior and the exterior users) using the received CQIs (Channel Quality Indicator) from F_2 and F_3 . To implement these techniques, we propose a threshold T_p as a parameter in the eNB such that users with uplink power higher than T_p are assigned as interior users, and vice versa. In a DAS-SFR, T_p can play the same role as a threshold for CQI such that users with CQI higher than T_p are assigned as interior users, and vice versa.

A. The Power Self-Optimization Algorithm

According to the above intuitive analysis, we propose a power self-optimization (PSO) technique which is based on a simple and decentralized algorithm that runs on the application layer.

In the PSO algorithm, the expected network gain, which is based on one or both system KPIs, is used in order to determine whether to increase or decrease the transmission power of the central DRUs. To do so, the PSO technique

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uses the KPI associated with each eNB to compute the system KPI. Finally, the central DRUs are in charge of adjusting ΔP based on system KPI by performing the PSO algorithm. FIG. 4 depicts the block diagram of the self-optimization algorithm. As illustrated in FIG. 4, both KPIs are functions of ΔP .

Observing the block diagram shown in FIG. 4, it is possible to note that the transmission power is adjusted by comparing the current KPI, calculated at the end of current phase, and the last KPI, calculated at the end of last phase. Moreover, it is important to highlight that the central DRUs have a predefined minimum and maximum transmission power (p^{min} and p^{max}), which cannot be exceeded by the algorithm. Thus, the self-optimization algorithm increases or decreases the ΔP step-by-step by p (dB) for each central

DRUs. Parameter t can take two values, 1 and -1, where 1 shows that algorithm starts by increasing the power level. Conversely, -1 indicates that the algorithm starts by decreasing the power level. Since we do not want the power to oscillate around the optimal power forever, we define the parameter c to help the algorithm stop.

Whenever the algorithm starts off by increasing the power level, the central DRUs increase the ΔP by the fixed parameter p . The central DRU keep increasing the power by the fixed parameters p as long as the current calculated KPI_{SU} is greater than the last calculated KPI_{SU} . If the current calculated KPI_{SU} is equal to last calculated KPI_{SU} , the central DRUs keep increasing the power as long as the current calculated KPI_{CSU} is not smaller than the last calculated KPI_{CSU} , otherwise it decreases its power level. Note that whenever the algorithm starts off by increasing the power level, all the above mentioned statements should be reversed i.e. the decreasing behavior should be changed to an increasing behavior and vice versa.

The PSO algorithm seeks to maximize the number of satisfied users meanwhile it seeks to maximize the capacity of the satisfied users in order to have a better QoS. Even though some embodiments do not achieve an optimal solution, the methods described herein provide stable power updates toward the optimal solution. In other embodiments, the optimal solution is obtained.

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Referring to FIG. 4, KPI_{SU} is the Key Performance Indicator for Satisfied Users and KPI_{CSU} is the key performance indicator for the Capacity of Satisfied Users. ΔP is the change in power of the carriers. By adjusting the power of the carriers, the number of satisfied users and the capacity of the satisfied users can be increased or optimized. Initially, t is set to 1, c is set to zero, $\Delta P=0$, and $p=1$ (i.e., the power increments are made in 1 dBm steps). In the illustrated embodiment, the maximum and minimum values of power (measured in dBm in an embodiment) are 20 and -10, respectively. In some implementations, the maximum and minimum power are set by the user and the values provided herein are merely given by way of example. Thus, depending on the system parameters, different values will be utilized for the maximum and minimum power. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

A measurement of the KPI_{SU} given ΔP (initially zero, for which the power of the various carriers is equal) is made and the result is assigned to KPI_{SU}^* . Thus, the performance for the users in a given cell is measured to determine the number of satisfied users in the cell. The capacity for the satisfied users is also measured at this value of ΔP (KPI_{CSU} given ΔP) and assigned to KPI_{CSU}^* .

The difference in power is then modified ($\Delta P+(t*p)$) in order to iterate on the difference in power. t is an updating index that has values of positive or negative one, indicating if the difference in power is being increased or decreased. Referring to FIG. 4, movement through the left hand side of the loop results in increases in power and movement through the right hand side of the loop results in decreases in power.

In order to determine if the power is in the correct range, a comparison is made between ΔP and the maximum power ($\Delta P > p^{max}$), between ΔP and the minimum power ($\Delta P < p^{min}$), and that an oscillation indicator (c) is not reached. If any of these conditions are true, then the method is terminated. Otherwise, if the power is within the predetermined range (less than maximum power and greater than the minimum power) and oscillation has not been detected, the method continues.

A measurement is made of the number of satisfied users given the new ΔP ($KPI_{SU}(\Delta P)$) and this measured value is compared to the previous number of satisfied users. If the change in power (an increase in this example) has resulted in a decrease in the number of satisfied users, then the right hand loop is used to toggle the updating index (t), which will enable the power to be decreased in the subsequent flow.

If, on the other hand, the number of satisfied users given the new ΔP is greater than or equal to the previous number of satisfied users, indicating no change or an increase in the number of satisfied users, the method proceeds to the next comparison to determine if the number of satisfied users given the new ΔP is equal to the previous number of satisfied users. If the comparison is not equal, then the left hand side of the loop is used to increase the power differential in the subsequent flow.

If the number of satisfied users given the new ΔP is equal to the previous number of satisfied users, then a measurement is made of the capacity of the satisfied users and this value is compared to the previous capacity. If the measured capacity is less than the previous capacity, the right hand side of the loop is used to decrease the power differential in the subsequent flow. If the measured capacity is greater than or equal to the previous capacity, then the left hand side of the loop is used to increase the power differential in the subsequent flow.

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Referring to FIG. 1, the method illustrated in FIG. 4 will be applied in relation to the carriers used in the central antenna (eNB0) of the cell (i.e., hexagon). For each cell, the carrier used in the peripheral portions of the cell will be used as a reference and the other carriers will have their power set by optimizing the number and capacity of satisfied users using the algorithm described herein. In some embodiments, the carriers used in the central antenna that are not used in the peripheral portions of the cell will have the same power, providing a single ΔP for the central antenna with the carrier used in the peripheral portions of the cell providing the reference. In some implementations, the carriers used only in the central antenna can have differing powers with the algorithm applied to the carriers individually (e.g., F_1 compared to F_3 and F_2 compared to F_3 for the rightmost cell in FIG. 1A).

Referring to FIG. 1A, F_1 is the reference for the top left cell, F_2 is the reference for the bottom left cell, and F_3 is the reference for the rightmost cell. One of ordinary skill in the art would recognize many variations, modifications, and alternatives. Embodiments of the present invention provide methods and systems in which the number of carriers in a cell can be increased, thereby increasing bandwidth. The algorithm is then used to set the power level of the added carriers to a level that reduced interference with adjacent cells to an acceptable level.

It should be appreciated that the specific steps illustrated in FIG. 4 provide a particular method of increasing a number and capacity of satisfied users by varying power between carriers according to an embodiment of the present invention. Other sequences of steps may also be performed according to alternative embodiments. For example, alternative embodiments of the present invention may perform the steps outlined above in a different order. Moreover, the individual steps illustrated in FIG. 4 may include multiple sub-steps that may be performed in various sequences as appropriate to the individual step. Furthermore, additional steps may be added or removed depending on the particular applications. One of ordinary skill in the art would recognize many variations, modifications, and alternatives.

V. Analytical and Simulation Results

FIGS. 5A-5B represent the ergodic capacity of a cellular DAS's central cell for different frequency reuse techniques versus the normalized distance from the eNB0 DRU0 in the direction of the worst case position X, for a path loss exponent of 3.76. Each scenario is plotted for the individual capacities $C^{(F_1)}$, $C^{(F_2)}$, $C^{(F_3)}$, and also for the total capacity C_{total} . These figures show an interesting non-monotonic relationship between capacity and the normalized distance from the base station. This is due to the fact that the signal from a distributed antenna module becomes dominant around 0.6 R.

As it can be observed in FIG. 5A, when applying the SFR methods, by increasing ΔP from -10 dB to 20 dB, the central cell's $C^{(F_2)}$ and $C^{(F_3)}$ increase. This, however, increases the interference associated with the edge DAUs of the neighboring cells which are using F_2 and F_3 as their main frequency band. It is necessary to note that, increasing ΔP from -10 dB to 20 dB, significantly increases the associated interference with the F_1 frequency band in the central cell, imposed from the neighboring cells, and thus decreases the central cell's $C^{(F_1)}$.

It is important to notice that, considering SFR methods, as power increases, C_{total} does not change harmonically, which means the ergodic capacity associated with the cell's interior regions increases, and that of the cell's exterior regions

decreases. Therefore, the users' distribution within the cell's area plays a significant role when deciding the optimal ΔP .

A secondary consideration when deciding the optimal ΔP is the minimum required capacity (C_{th}). As an example, with a high C_{th} (ergodic capacity=20 bit/Hz in FIGS. 5A and 5B), as ΔP increases, a wider radiance in a cell will be covered by ergodic capacity higher than 20. With a low C_{th} (ergodic capacity=3 bit/Hz in FIGS. 5A and 5B), as ΔP increases, a shorter radiance in the cells will be covered by ergodic capacity higher than 3.

The FFR method fully uses the frequency bands, therefore, the cell's interior regions' achieved an ergodic capacity higher than ergodic capacity in the cell's interior regions when applying the HFR3 method. For example, at ergodic capacity=20, the FFR method outperforms the HFR3 method, considering the users' satisfaction probability. However, when applying the FFR method, due to the interference caused by the neighboring cells, the edge cells frequently experience dead spots. As an example, considering the users' satisfaction probability, for ergodic capacity=3, the HFR3 method outperforms the FFR method.

FIGS. 6A-D and 7A-7D demonstrate the two KPI_{SU} and KPI_{CSU} for different ΔP , considering four different user distributions. The only parameter that is different in the aforementioned figures is their C_{th} , i.e. we consider low $C_{th}=0.01 W_{RB}$ and high $C_{th}=0.07 W_{RB}$, in FIGS. 6A-6D and FIGS. 7A-7D, respectively. In theoretical analysis, the interior region is distinguished from the exterior region, based on T_p . In other words, the region with ergodic capacity higher than T_p is considered as interior region, and the region with ergodic capacity lower than T_p is considered as exterior region. This T_p is associated to the region's ergodic capacity of the frequency bands that are only allocated to the central DRUs. We assume $T_p=2$ (bit/Hz) in our theoretical analyses.

Since both KPI functions are dependent on G_k , it is reasonable to consider each of these functions as a criteria to measure the QoS. We analyze two different cases, i.e. ($w_1=1, w_2=0$) and ($w_1=0, w_2=1$). In the first case, we presume KPI_{SU} as our QoS function whereas in the second case we consider KPI_{CSU} as our QoS function.

We define our user distributions as depicted in Table 1. where

$$N_{user}^{total} = \sum_i X_i S_i,$$

ie {region A, region B, region C, region D}, S_i is the area of region i and $X_i=(\# \text{ users of region i})/S_i$. We perform Monte Carlo simulations to corroborate the analytical results. It is assumed that the total number of users (N_{user}^{total}) is 200.

As it is seen in FIGS. 6A-6D, when C_{th} takes a low value, i.e. $C_{th}=0.01 W_{RB}$, except for the FFR method, applying the rest of the frequency reuse methods (HFR3, SFR) results in the highest number of the satisfied users (KPI_{SU}). Note that, as ΔP increases, when applying DAS-SFR, the number of the satisfied users asymptotically decreases. The above mentioned results hold for all four different user distributions: FIG. 6A: User's Distribution=Uniformity; FIG. 6B: User's Distribution=Dense at the Center; FIG. 6C: User's Distribution=Dense at the middle of Center and Edge Cell; and FIG. 6D: User's Distribution=Dense at the Edge Cell.

As was shown in FIGS. 6A-6D, there exists an optimal ΔP at which the KPI_{CSU} is maximum, for all four different distributions. For instance, when applying the DAS-SFR-

Scenario3 method, for the UD, DCD, DCED and DED, the maximum KPI_{CSU} happens at $\Delta P=-5$ dB, 2 dB, 8 dB, and -4dB, respectively.

One has to consider, the optimal ΔP is different for dissimilar distribution scenarios. Moreover, the DAS-SFR-Scenario3 method outperforms the other two DAS-SFR methods, for all the distributions under consideration.

FIGS. 7A-7D reveal that, when C_{th} takes a large value, i.e. $C_{th}=0.07 W_{RB}$, the FFR method outperforms the HFR3 method, considering the number of the satisfied users (KPI_{SU}). This corroborates our analytical results from FIGS. 5A-5B, as it was explained previously. However, the DAS-SFR-Scenario2 method outperforms all the other methods, at different optimal ΔP values for dissimilar distribution scenarios.

As it can be perceived from FIGS. 7A-7D, there exists an optimal ΔP at which the KPI_{SU} and KPI_{CSU} are maximum, for all four different distributions: FIG. 7A: User's Distribution=Uniformity; FIG. 7B: User's Distribution=Dense at the Center; FIG. 7C: User's Distribution=Dense at the middle of Center and Edge Cell; and FIG. 7D: User's Distribution=Dense at the Edge Cell. As an example, when applying the DAS-SFR-Scenario2 method, for the UD, DCD, DCED and DED, the maximum KPI_{SU} and KPI_{CSU} happen at $\Delta P=6$ dB, 4 dB, -2 dB, and 13 dB, respectively.

Note that, the optimal ΔP is different for different distribution scenarios. Moreover, the DAS-SFR-Scenario2 method outperforms the other two SFR methods, for all distributions under consideration. Since the DAS-SFR-Scenario2 uses all the frequency bands in the interior cell region, along with the fact that the users with throughput above the C_{th} are mainly located in the interior cell region, leads to the final conclusion that DAS-SFR-Scenario2 outperforms the other methods.

The capacity of the above mentioned architectures is also investigated through system level simulations. We consider the two-ring hexagonal cellular system with nineteen eNBs, such that each cell has 7 DRUs, as depicted in FIG. 2, where the eNBs distance is 500 meters. The 200 UEs are distributed for 4 user distribution methods which are defined in Table 1. An eNB allocates the available RBs to UEs by estimating the signaling and uplink power of UEs. We use the simulation parameters listed in Table 2.

At a TTI (Transmission Time Interval) for the simulation, the eNB in a cell gathers the CQI (Channel Quality Indicator) information of UEs and allocates the RBs to each UE, using the Round Robin scheduling technique. The throughput of a UE is obtained based on the SINR of the UE in the assigned RB. In system level simulation, SINR is determined by the path loss and lognormal fading measured in RB. The throughput of a UE_m is estimated using the Shannon capacity as follows

$$C_m^{(f)} = W_{RB}^{(f)} \log(1 + \text{SINR}_m^{(f)}), f = F_1, F_2, F_3 \quad (21)$$

where, $W_{RB}^{(f)}$ is the bandwidth of RBs assigned to a UE and $\text{SINR}_m^{(f)}$ is the SINR of a UE_m . The cell capacity in each region is the total throughput of UEs in the corresponding region and is expressed as follows

$$C_{total} = \sum_{i=1}^3 \sum_{m=1}^M C_m^{(F_i)} \quad (22)$$

Where M is the number of UEs in a group.

The presented numerical results corroborate the analytical results depicted in FIG. 6 and FIG. 7.

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Embodiments of the present invention provide a new cell architecture combining two inter-cell interference mitigation techniques, Distributed Antenna System and Soft Frequency Reuse, to improve cell edge user's throughput when the system has full spectral efficiency. A power self-optimization algorithm that aims at maximizing the number of satisfied users while trying to increase their capacity was also proposed. In more detail, the self-optimization algorithm uses the KPIs computed by the server in the last phase and current phase to adjust the power level for the next phase.

An analytical framework is derived to evaluate the user throughput leading to tractable expressions. A natural extension of this work is to address the cellular uplink. The overall capacity increases by using the SFR technique, since the spectral efficiency in the interior region is higher than that in the exterior region when compared to HFR3 technique. The cell edge user's throughput increases by using the SFR technique; since the interference signal from neighbor cells is lower than that the time we use FFR technique.

Analytical and simulation results demonstrated the advantage of using the self-optimization algorithm instead of setting a fixed power level. When a DAS-SFR without the PSO algorithm is considered, the transmission power is set at the beginning of the communication and remains the same during its entire network lifetime. This characteristic can be negative considering a DAS-SFR in a real environment where the inherent user distribution is not constant.

Due to the fact that the inherent environment user distribution is completely variable, the PSO algorithm always guarantees the maximum number of satisfied users during the communication, while the algorithm serves to maximize their capacity as well.

TABLE 1

	$X_i/n, i \in \{A, B, C, D\}$					
	R_1	R_2	UD ⁽¹⁾	DCD ⁽²⁾	DCED ⁽³⁾	DED ⁽⁴⁾
Region A	0	0.25	1	7	1	1
Region B	0.25	0.50	1	1	7	1
Region C	0.50	0.75	1	1	1	1
Region D	0.75	1	1	1	1	7

⁽¹⁾UD: Uniform Distribution

⁽²⁾DCD: Dense at the Center Distribution

⁽³⁾DCED: Dense at the mid. of Cent. And Edge cell Distribution

⁽⁴⁾DED: Dense at the Edge cell Distribution

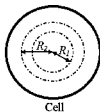


TABLE 2

Simulation Parameters	
PARAMETERS	VALUE
Channel Bandwidth for each Frequency Part	5 MHz
Carrier Frequency	2.14 GHz
FFT size	1024
Number of Resource Blocks for each Frequency Part	25

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TABLE 2-continued

Simulation Parameters	
PARAMETERS	VALUE
Subcarrier Spacing	15 kHz
Cellular Layout	Hexagonal grid, 19 sites
Inter-eNB Distance	500 meters
Log-normal Shadowing	8 dB
Propagation loss	$128.1 + 37.6 \log_{10}(R(\text{km}))$
White Noise Power Density	-174 dBm/Hz
Scheduling	Round Robin
TTI	1 ms
T_p (CQI)	2 CQI

What is claimed is:

1. A method of determining a transmission power of a digital remote unit (DRU) in a distributed antenna system (DAS), the method comprising:

- setting a transmission power level for a DRU;
- determining a first key performance indicator related to a number of satisfied users at the transmission power;
- iteratively adjusting the transmission power level for the DRU to increase the first key performance indicator related to the number of satisfied users;
- determining a second key performance indicator related to a capacity for the number of satisfied users;
- iteratively adjusting the transmission power level for the DRU to increase the second key performance indicator related to the capacity for the number of satisfied users; and
- setting the transmission power level for the DRU at an iterated power level.

2. The method of claim 1 wherein the transmission power comprises a differential between a reference carrier and one or more carriers.

3. The method of claim 2 wherein the reference carrier comprises a first frequency carrier, and the one or more carriers comprise a second frequency carrier and a third frequency carrier.

4. The method of claim 2 wherein the reference carrier is utilized by multiple antennas of the DRU and the one or more carriers are utilized by a single antenna of the DRU.

5. The method of claim 4 wherein the single antenna is a center antenna of the DRU.

6. The method of claim 5 wherein the multiple antennas are edge antennas of the DRU.

7. The method of claim 6 wherein the multiple antennas comprise six antennas.

8. The method of claim 1 wherein the second key performance indicator related to the capacity for the number of satisfied users is a number of users having a capacity above a predetermined threshold capacity.

9. The method of claim 8 wherein the predetermined threshold capacity is defined by a predetermined threshold bit rate.

10. The method of claim 1 further comprising: determining that the transmission power is outside a predetermined range; and terminating the method.

11. The method of claim 1 further comprising: determining that an oscillation indicator is equal to a predetermined value; and terminating the method.

* * * * *

EXHIBIT C

Corning

Mid-Power Remote Unit (MRU)
User Manual

CORNING

Warranties

Hardware Warranty

Corning warrants to the original purchaser (“Customer”) that for the duration of the warranty period, one (1) year, commencing on the date of shipment of the Hardware, unless otherwise agreed in writing by Corning (the “Hardware Warranty Period”), the Hardware furnished by Corning shall be free in all material respects from defects in material and workmanship, and shall conform to the applicable portions of the Specifications, as defined below (the “Hardware Warranty”). If notified by Customer of any such defects in material or workmanship or nonconformity with applicable portions of the Specifications within the Hardware Warranty Period, Corning shall promptly, at its own election and expense, repair or replace any such Hardware proven to be defective under the terms of this Hardware Warranty. Such repair or replacement shall be Customer’s sole remedy and Corning sole obligation in the event this Hardware Warranty is invoked. If any components comprising a part of the Hardware are replaced or repaired during the Hardware Warranty Period, the Hardware Warranty Period for such repaired or replaced components shall extend to the longer of (i) the balance of the Hardware Warranty Period or (ii) three (3) months from the date of repair or replacement. For purposes of this Warranty, “Specifications” shall mean the specifications and performance standards of the Products as set forth in documents published by Corning and delivered to Customer which contain technical specifications or performance standards for the Products.

If Customer invokes this Hardware Warranty, it shall notify Corning promptly of the claimed defect. Customer will allow Corning to inspect the Hardware at Customer’s location, or to return the Hardware to Corning closest repair facility. For Hardware returned to Corning repair facility, Customer shall be responsible for payment of all transportation and freight costs (including insurance) to Corning’s repair facility, and Corning shall be responsible for all transportation and freight costs (including insurance) incurred in connection with the shipment of such Hardware to other repair facilities of Corning and/or its return to Customer.

Notwithstanding the foregoing, in no event will Corning be liable for damage to Products resulting from improper handling during or after shipment, misuse, neglect, improper installation, operation or repair (other than by authorized Corning personnel), alteration, accident, or for any other cause not attributable to defects in materials or workmanship on the part of Corning. Corning shall not reimburse or make any allowance to Customer for any labor charges incurred by

Customer for replacement or repair of any goods unless such charges are authorized in advance in writing by Corning.

Software Warranty

Corning warrants to the original purchaser (“Customer”) that for the duration of the warranty period, one (1) year, commencing on the date of shipment of the Software, unless otherwise agreed in writing by Corning (the “Software Warranty Period”), the Software shall conform with, and perform the functions set forth in the Specifications, and shall be free from defects in material or workmanship (the “Software Warranty”). In the event the Software is proven to be defective under the terms of this Software Warranty, Corning shall correct such defects or failure and ensure that the Software conforms with, and performs the functions set forth in, the Specifications. Customer will allow Corning to inspect the Software at Customer’s location or to return it to Corning’s closest repair facility. Notwithstanding the foregoing, Corning shall have no obligation under the Software Warranty if the Software is modified or used with hardware or software not supplied or approved by Corning or if the Software is subject to abuse, improper installation or application, accident, electrical or environmental over-stress, negligence in use, storage, transportation, or handling. Third-party software distributed with the Software may carry certain warranties which, to the maximum extent allowed by law, Corning hereby assigns, transfers and otherwise conveys to Customer, provided, however, that Corning itself provides no warranty of any kind, express, implied, statutory or otherwise, for any third-party software provided hereunder.

Corning does not warrant any hardware, software, or services not provided by Corning.

THIS WARRANTY IS THE ONLY WARRANTY MADE BY CORNING AND IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. CORNING SHALL NOT BE LIABLE FOR ANY OTHER DAMAGE INCLUDING, BUT NOT LIMITED TO, INDIRECT, SPECIAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF OR IN CONNECTION WITH FURNISHING OF GOODS, PARTS AND SERVICE HEREUNDER, OR THE PERFORMANCE, USE OF, OR INABILITY TO USE THE GOODS, PARTS, AND SERVICE. CORNING SALES AGENTS OR REPRESENTATIVES ARE NOT AUTHORIZED TO MAKE COMMITMENTS ON WARRANTY RETURNS.

Returns

In the event that it is necessary to return any product against above warranty, the following procedure shall be followed:

1. Return authorization is to be received from Corning prior to returning any unit. Advise Corning of the model, serial number, and discrepancy. The unit may then be forwarded to Corning, transportation prepaid. Devices returned collect or without authorization may not be accepted.
2. Prior to repair, Corning will advise the customer of our test results and any charges for repairing customer-caused problems or out-of-warranty conditions etc.
3. Repaired products are warranted for the balance of the original warranty period, or at least 90 days from date of shipment.

Limitations of Liabilities

Corning's liability on any claim, of any kind, including negligence for any loss or damage arising from, connected with, or resulting from the purchase order, contract, quotation, or from the performance or breach thereof, or from the design, manufacture, sale, delivery, installation, inspection, operation or use of any equipment covered by or furnished under this contract, shall in no case exceed the purchase price of the device which gives rise to the claim.

Except as expressly provided herein, Corning makes no warranty, expressed or implied, with respect to any goods, parts, and services provided in connection with this agreement including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose. Corning shall not be liable for any other damage including, but not limited to, indirect, special or consequential damages arising out of or in connection with furnishing of goods, parts and service hereunder, or the performance, use of, or inability to use the goods, parts, and service.

Note: The grantee is not responsible for any changes or modifications not expressly approved by the party responsible for compliance. Such modifications could void the user's authority to operate the equipment.

Reporting Defects

The units were inspected before shipment and found to be free of mechanical and electrical defects. Examine the units for any damage that may have been caused in transit.

If damage is discovered, file a claim with the freight carrier

immediately. Notify Corning as soon as possible in writing.

Note: Keep all packing material until you have completed the inspection.

Warnings and Admonishments

There may be situations, particularly for workplace environments near high-powered RF sources, where recommended limits for safe exposure of human beings to RF energy could be exceeded. In such cases, restrictive measures or actions may be necessary to ensure the safe use of RF energy.

The equipment has been designed and constructed to prevent, as far as reasonably, practicable danger. Any work activity on or near equipment involving installation, operation or maintenance must be, as far as reasonably, free from danger.

Where there is a risk of damage to electrical systems involving adverse weather, extreme temperatures, wet, corrosive or dirty conditions, flammable or explosive atmospheres, the system must be suitably installed to prevent danger. Equipment provided for the purpose of protecting individuals from electrical risk must be suitable for the purpose and properly maintained and used. This covers a range of activities including lifting, lowering, pushing, pulling, carrying, moving, holding, or restraining an object, animal, or person from the equipment. It also covers activities that require the use of force or effort, such as pulling a lever or operating power tools.

Where some of the above mentioned activities are required, the equipment must be handled with care to avoid being damaged.

Observe standard precautions for handling ESD-sensitive devices. Assume that all solid-state electronic devices are ESD sensitive. Ensure the use of a grounded wrist strap or equivalent while working with ESD-sensitive devices. Transport, store, and handle ESD-sensitive devices in static-safe environments.

Regulatory Compliance Information

WARNINGS!

- This is **NOT** a **CONSUMER** device. It is designed for installation by **FCC LICENCEES** and **QUALIFIED INSTALLERS**. You **MUST** have an **FCC LICENSE** or express consent of an FCC license to operate this device. Unauthorized use may result in significant forfeiture penalties, including penalties in excess of \$100,000 for each continuing violation.

- **ANTENNAS:** Use only authorized and approved antennas, cables, and/or coupling devices! The use of unapproved antennas, cables, or coupling devices could cause damage and may be of violation of FCC regulations. The use of unapproved antennas, cables, and/or coupling devices is illegal under FCC regulations and may subject the user to fines. See Section 3.6 of this document.

RF Safety

To comply with FCC RF exposure compliance requirements:

ATTENTION!

Compliance with RF safety requirements:

- Corning products have no inherent significant RF radiation.
- The RF level on the downlink is very low at the downlink ports. Therefore, there is no dangerous RF radiation when the antenna is not connected.

CAUTION!

Use of controls, adjustments, or performance of procedures other than those specified herein may result in hazardous radiation exposure.

Warning! Antennas used for this product must be fixed mounted on indoor permanent structures, providing a separation distance of at least 100 cm from all persons during normal operation.

Warning! Each individual antenna used for this transmitter must be installed to provide a minimum separation distance of 100 cm or more from all persons and must not be co-located with any other antenna for meeting RF exposure requirements.

Warning! Antenna gain should not exceed 12.5 dBi.

Warning! The design of the antenna installation needs to be implemented in such a way so as to ensure RF radiation safety levels and non-environmental pollution during operation.

Laser Safety

- Fiber optic ports of the Corning optical network evolution (ONE™) solutions emit invisible laser radiation at the 1310/1550 nm wavelength window.
- External optical power is less than 10 mW, internal optical power is less than 500 mW.
- To avoid eye injury never look directly into the optical ports, patch cords, or optical cables. Do not stare into beam or view directly with optical instruments. Always assume that optical outputs are on.

- Only technicians familiar with fiber optic safety practices and procedures should perform optical fiber connections and disconnections of Corning optical network evolution (ONE) solutions devices and the associated cables.
- Corning optical network evolution (ONE) solutions MRU has been tested and certified as a Class 1 laser product to IEC/EN 60825-1 (2007). It also meets the requirements for a Hazard Level 1 laser product to IEC/EN 60825-2:2004 to the same degree.
- Corning optical network evolution (ONE) solutions MRU complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50 (2007).

Care of Fiber Optic Connectors

- Do not remove the protective covers on the fiber optic connectors until a connection is ready to be made. Do not leave connectors uncovered when not connected.
- The tip of the fiber optic connector should not come into contact with any object or dust.

Company Certification

ISO 9001:2000 and ISO 13485:2003

Licensee Contact Information

Industrial boosters may only be used by FCC licensees or those given express (individualized) consent of license. Corning Optical Communications Wireless certifies all of the VARs listed as licensed installers for Corning. For the list of licensed VARs, please contact the Tech Support Hotline: 410-553-2086 or 800-787-1266.

About This Manual

This user guide provides all the information necessary to understand the architecture and general installation procedures and requirements of the Corning optical network evolution (ONE) solutions mid-power remote unit (MRU).

Note: The commissioning procedure, monitoring and management capabilities, and configuration options of Corning optical network evolution (ONE) solutions elements are described in the Corning optical network evolution (ONE) solutions HCM and Web management user manual.

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Introduction

The MRU is a mid-power (2 W) remote solution for the Corning optical network evolution (ONE™) solutions. The MRU provides remote indoor and outdoor coverage. It is a fiber-fed, compact, and scalable multiservice solution designed to complement the Corning optical network evolution (ONE) solutions by providing complete RF open space coverage for large-scale public venues such as campus applications.

The MRU consists of a compact enclosure that houses the RF modules, power elements, and the required interfaces, supporting up to seven bands in various combinations. It enables multiple wireless technologies and operator services to be distributed over a single broadband infrastructure. The MRU can be deployed in new sites or alongside existing lower-power RAU/RAU5 remotes, sharing a common headend and element management system. Alongside Corning optical network evolution (ONE) solutions deployments, the MRU provides a comprehensive indoor and outdoor coverage solution for varying site requirements, supporting everything from high-rise buildings and campus topologies to stadiums and airports.

Management and configuration options are provided for each MRU service via a Web session to the headend control module (HCM v1.6 and higher). The HCM enables centralized, single-source local and remote management of all system elements.



Mid-Power Remote Unit (MRU) | Figure 1-1

1.1 Key Features and Capabilities

- **Multi-frequency/multiservice platform** – supports LTE 700, ESMR, CELL, PCS, AWS, and WCS (including an integrated 2.5 GHz add-on port), accommodating GSM, CDMA, UMTS, LTE, and more.
- **Multioperator-optimized platform** – services from a number of operators can be distributed by the same unit.
- **Cost-effective higher power** – optimizes and reduces the number of antennas required to cover open areas by offering up to 33 dBm (2 W) composite power per frequency band.
- **Operator-grade performance** – advanced signal handling, RF filtering, and management ensures operator-grade performance.
- **Optical fiber savings** – all services routed to an MRU are routed over a single optical fiber pair.
- **Design and deployment flexibility** – MRU available in AC or DC power supply options. Antenna splitting schemes are possible due to the higher power output capability.
- **Modular and scalable design** – modular design enables adding new wireless services easily and cost-effectively without disruption to workspaces or existing services. Supports external 2.5 GHz RF source.
- **Simple installation and maintenance** – all connections and status LEDs located on the front panel. MRU is modular, hot swappable, and field upgradable.
- **Management and control** – alarm forward to NOC or standard element management system (EMS) via SNMP, software controlled output power, and optical link auto gain control.

1.2 General System Specifications and Requirements

1.2.1 Environmental and Regulatory Specifications

	Operating	Storage
Temperature	-40° to +65°C (-40° to 149°F)	-30° to 85°C (-22° to 185°F)

Table 1-1. Temperature and Humidity Specifications

1.2.2 Safety and Regulatory Approvals

Regulation/Standard Category	Approval
Laser Safety	FDA/CE 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50 and IEC 60825-1
EMC	FCC 47 CFR Part 15, 22, 24, 27
Safety	UL 60950 IEC 60825-1:2007 IEC 60825-2:2010 CAN/CSA-C22.2 No. 60950-1-03
NEBS	GR-63, GR-1089 (with outdoor enclosure)

Table 1-2. Safety and Regulatory Approvals

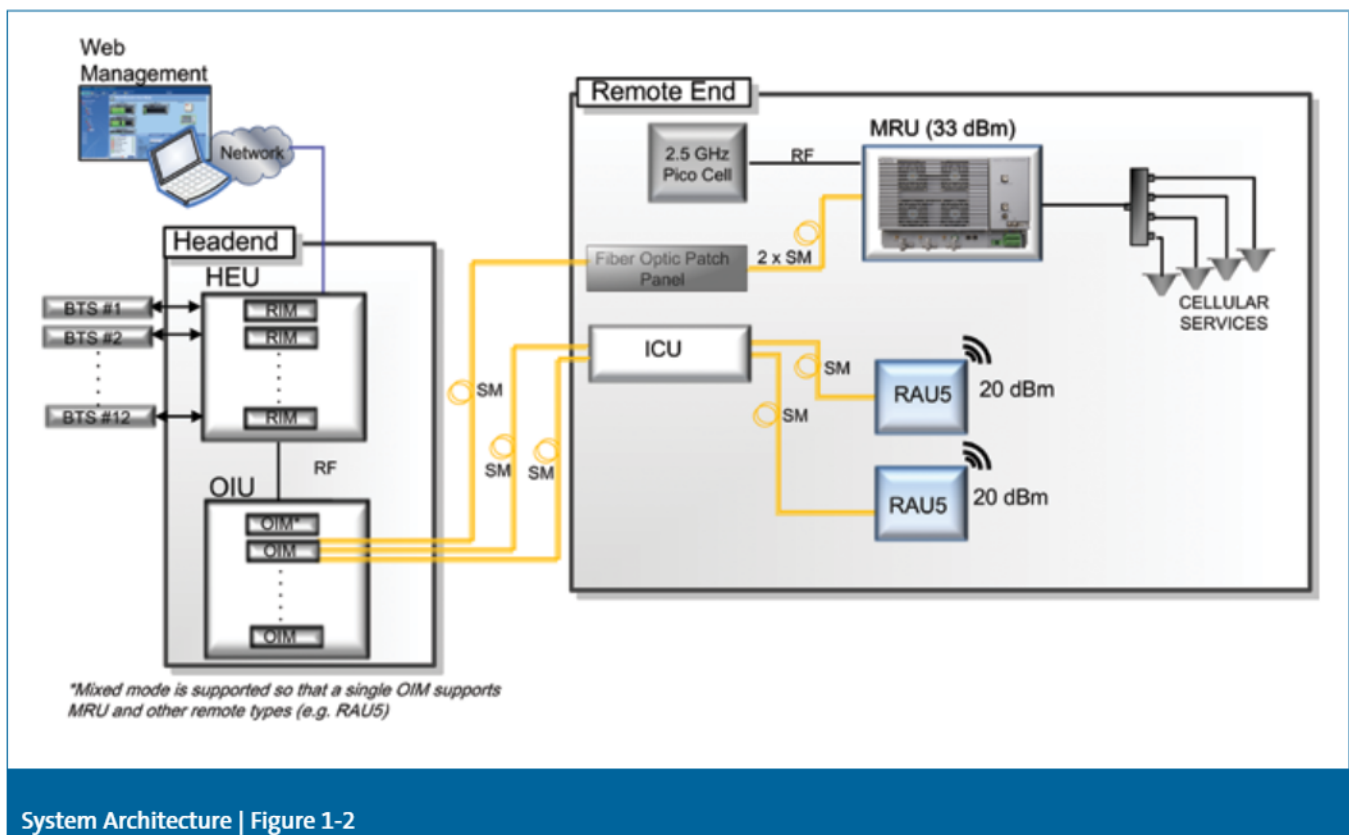
1.2.3 Power Specifications

Power Specification	Description
Power Consumption (maximum)	360 W (for fully loaded chassis)
AC Power Input	100-240 VAC/50-60 Hz
Maximum AC Current Consumption	5 A
DC Power Input	DC class 1: 48 VDC (40-60 VDC), 9 A maximum DC class 2: 24/48 VDC (20-60 VDC) Power amplifier consumption per pair: 50 W Maximum power consumption: 330 W Maximum current consumption: 1.75 A per pair Maximum current draw per pair: 64 W

Table 1-3. MRU Power Specifications

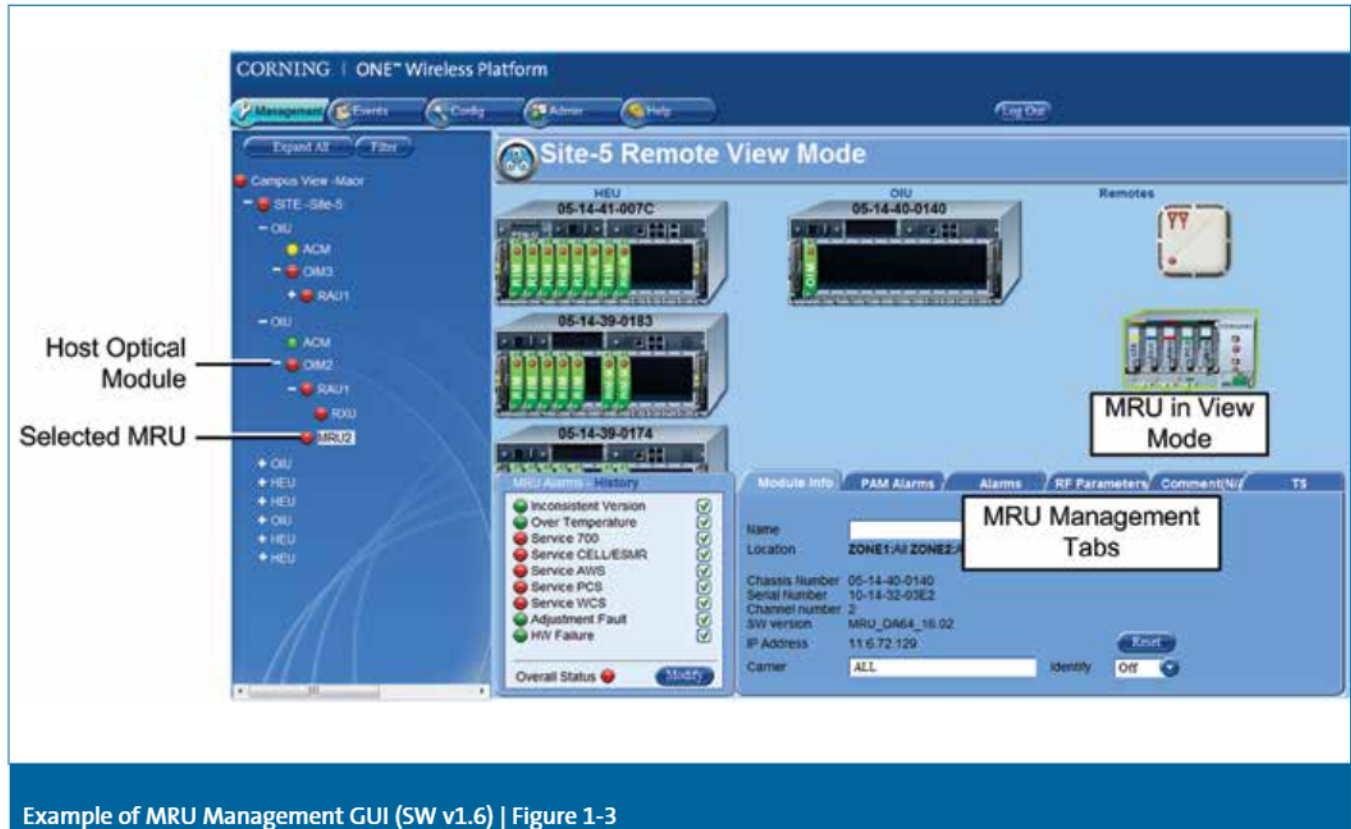
1.3 System Architecture

Figure 1-2 illustrates the MRU system architecture. In the downlink, at the headend, BTS/BDA RF signals are conditioned by service-specific RIMs installed in the headend unit (i.e. HEU/IHU), ensuring a constant RF level. The conditioned signals are then forwarded to the OIU and converted by the OIMs to an optical signal for transporting over single-mode fiber to the MRUs at the remote locations. All mobile services are combined and distributed through a single antenna port over the broadband antenna infrastructure installed at the remote locations. In the uplink, the process is reversed. As illustrated in the system architecture shown in Figure 1-2, all mobile services are combined and distributed through a single antenna port over the broadband antenna infrastructure installed at the remote locations.



1.4 System Monitoring and Management

The MRU is centrally managed via the headend control module software management application (v1.6 and higher). Figure 1-3 shows the management tabs of the selected MRU. Refer to the “Headend Control Module (HCM) and Web Management GUI v1.6” user manual (CMA-423-AEN) for information on how to configure and manage the MRU.



Example of MRU Management GUI (SW v1.6) | Figure 1-3

MRU Interfaces

This chapter provides detailed descriptions of the MRU chassis and main modules and interfaces. This content includes port and LED interface descriptions. The MRU comprises the following main modules:

- Power amplifier modules (PAM) – internal service-specific power amplifier module that interfaces to an optical interface module (OIM) at the headend site via a single-mode pair and supports one service. MRU supports up to seven bands. The PAM provides the additional amplification on the DL signals routed from the OIM toward the multiplexer. PAMs are pre-installed in designated slots according to supported band.
- Multiplexer – combines the UL and DL RF signals of the supported services in addition to external RF signal (future option for connecting to external 2.5 GHz signal source) while providing the proper filtering into a single duplexed antenna port.

- Optical Module – includes the fiber optic, RF expansion, and external alarm interfaces.
- Power supply module (PSM) – local AC or remote DC power feed (model dependent).
- Fan module (FAM) – integrated fan module comprised of four fans which are also monitored via the Web GUI.

The MRU includes front panel interfaces (e.g. antenna, fiber optic connections, and LED status indicators) as well as status indicators per each internal module (which are accessed by opening the cabinet door). The following sections provide details on the front panel and internal module interfaces.



MRU Main Modules | Figure 2-1



CORNING

Port	Description
PSM Power Connector	<p>Model dependent:</p> <p>AC models – AC connector connected to power source using provided AC power cable only</p> <p>DC models – two types of terminal block connectors:</p> <ul style="list-style-type: none"> • CLASS2 (default) – two “DC In” 8-pin terminal block connectors for remote feed: one pair for each PAM (total of five pairs) and one pair for the FAM and OPTM; one RSV pair • CLASS1 – one “DC-In” 2-pin terminal block for local plant feed
Exp. UL/DL	SMA RF ports for UL and DL connections to add-on unit (supporting any band across the supported spectrum: 300 MHz to 3 GHz)
List. Mode	N/A
OPTIC	LC APC port for single-mode fiber connection
MGMT	RJ45 Ethernet connection for MRU local management connection
External Alarms	DB9 female external alarm connector for external dry contact alarm connections
Exp.	RJ45 Ethernet connection for add-on local craft

Table 2-1. MRU Interface Ports

LED	Description
PWR	<p>Steady green: Required power is supplied to MRU chassis</p> <p>Off: No power input detected</p>
RUN	<p>Blinking green: Unit is running and operational</p> <p>Rapid blinking green: “Identify” feature has been enabled via the management GUI</p> <p>Off: No power input detected</p>
STS	<p>Steady green: Normal operation; overall status OK</p> <p>Steady red: Indicates generated alarm in unit</p> <p>Blinking red: “Over temperature” alarm active, indicates temperature has exceeded threshold (with door open)</p> <p><i>Note: Temperature alarm is set as first priority and overrides any other alarm indicator.</i></p>
FAM	<p>Steady green: All four fans are operating at normal speed (fan alarms clear)</p> <p>Steady red: Fault detected in at least one fan (fan alarm set)</p>
LINK	<p>Steady green: Optical link level from optical module above normal threshold</p> <p>Steady red: Optical link level is lower than normal threshold</p>
(PAM)	<p>Steady green: Power and status of power amplifier module OK. No alarms active</p> <p>Steady red: One or more alarms are active</p>

Table 2-2. MRU LED Descriptions

Installation Guidelines

CHAPTER 3

This chapter provides installation guidelines for the Corning optical network evolution (ONE™) solutions MRU. The following installation rules are based on the assumption that the site survey and installation planning (including power requirements) have been completed. This preparation includes planning the distribution of antennas to provide the required coverage, as well as planning the layout of the devices and cables in the telecom closet or shaft.

3.1 Site Considerations

- The distance between the MRU service antenna and the coverage area should correspond to line of sight (LoS) requirements for maximum coverage area.
- The maximum fiber path loss is 5 dB.
- The system delay of the optical system must be taken into consideration when there are neighboring BTS sites overlapping in coverage.

3.2 Safety Guidelines

Before installing the equipment, review the following safety information:

- Follow all local safety regulations when installing the equipment.
- Only qualified personnel are authorized to install and maintain the repeater.
- Ground specified equipment with the provided grounding bolt.
- Do not use the grounding bolt to connect external devices.
- Follow electrostatic discharge (ESD) precautions.
- Use low-loss cables to connect the antennas.

3.3 Installation Requirements

- Mounting surface shall be capable of supporting the weight of the equipment.
- In order to avoid electromagnetic interference, a proper mounting location must be selected to minimize interference from electromagnetic sources such as large electrical equipment.
- Working space available for installation and maintenance for each mounting arrangement.
- Ensure unrestricted airflow.
- Ensure grounding connector is within reach of the ground wire.
- Ensure a power source is within reach of the power cord and the power source has sufficient capacity.
- Where appropriate, ensure unused RF connectors are terminated.
- Do not locate the equipment near large transformers or motors that may cause electromagnetic interference.
- Reduce signal loss in feeder cable by minimizing the length and number of RF connections.
- Ensure the equipment is operated within the stated environment (refer to Appendix A: Specifications or unit datasheet).
- Where appropriate, confirm availability of suitably terminated grade of RF and optical fiber.
- Observe handling of all cables to prevent damage.

3.3.1 Rack Safety Instructions

The following guidelines are relevant to the rack installed units. Review the following guidelines to help ensure your safety and protect the equipment from damage during the installation.


- Only trained and qualified personnel should be allowed to install or replace this equipment.
- The equipment has been designed to operate at the temperature range as stated in the product specifications. Verify that ambient temperature of the environment does not exceed the maximum MRU operating temperature of 65°C (149°F).
- **IMPORTANT!** If installed in a closed or multi-unit rack assembly, the operating ambient temperature of the rack environment may be greater than the room ambient. Therefore, ensure that the installation environment complies with the maximum MRU operating temperature.
- Ensure that adequate airflow and ventilation within the rack and around the installed components so that the safety of the equipment is not compromised. It is recommended to allow for at least about 1 in of airspace between devices in the rack.
- Verify that the equipment is grounded as required – especially in installations using supply connections other than direct connections to the branch circuit (e.g. use of power strips).

3.3.2 Rack Installation Guidelines

- To maintain a low center of gravity, ensure that heavier equipment is installed near the bottom of the rack and load the rack from the bottom to the top.
- Verify that the rack height can support the unit to be installed (MRU rack height = 6U), where you may also want to consider future installations.

3.4 Power Requirements

3.4.1 Power Safety Instructions

 **SAFETY WARNINGS!** When installing or selecting the power supplies:

- For AC models – only use the provided AC power cable (straight, U.S. 10 A, UL, L = 1.8-2.5 m, black, 110 V) to connect the power supply to the MRU.
- Be sure to disconnect all power sources before servicing.
- Calculate the required power according to the requirements of the specific installation and then determine the configuration of the power supplies. The required DC cables will then be determined by the selected power supply configuration.
- Use only UL-approved power supplies.
- Install external overcurrent protective devices for the system according to the power specifications described in Section 1.2.3.

3.4.2 Types of Power Supplies

Corning supplies various power supplies that can be installed in a rack or mounted on a wall, depending on your configuration.

3.4.3 Circuit Breakers

Calculate the required fuse protection while referring to power specifications described in Appendix A: Specifications. When installing fuse protections for the system, make sure to take into account other Corning system elements that may require external fuse protection as well.

3.4.4 Cable Routing

Ensure all cables, e.g. power cable, feeder cable, optical fiber, commissioning cable, connecting are properly routed and secured to avoid damage.

3.5 RF Coaxial Cable Guidelines

3.5.1 General RF Cable Installation Procedures

Note: The installer should be familiar with the ANSI/TIA/EIS-568 Cabling Standard guidelines.

- Observe the general cable installation procedures that meet with the building codes in your area. The building code requires that all cabling be installed above ceiling level (where applicable). The length of cable from the risers to each antenna must be concealed above the ceiling.
- The cable must be properly supported and maintained straight using Velcro® cable ties, cable trays, and clamps or hangers every 10 ft (where practical above ceiling level). Where this is not practical, the following should be observed:
 - The minimum bending radius of the supplied 1/2-in coax cable should be 7 in.
 - Cable that is kinked or has a bending radius smaller than 7 in must be replaced.
 - Cable runs that span less than two floors should be secured to suitably located mechanical structures.
 - The cables should be supported only from the building structure.
- All cables shall be weather-resistant type.
- Cable length is determined by the system installation plan. When calculating the cable length, take into account excess cable slack so as not to limit the insertion paths.

3.5.2 RF Rules

- Use coax RG-223, 50 Ohm, male-to-male QMA to N-type for RF connections from the RIMs to the BTS and 4.3-10 type for MRU.
- When using the Corning remote unit in an environment in which other indoor coverage systems are installed, it is recommended (where possible) that the antennas are placed at least 2 m apart.
- When bending coax cables, verify that the bending radius does not exceed the coax specifications.
- Use wideband antennas supporting a range of 300 MHz to 3 GHz.

- Terminate all unused MRU RF ports with a 50 Ohm load.
- Make sure that the VSWR measured at the coax cable meets the product specification. The VSWR must be measured before terminating the MRU RF ports in the remote communication rooms.

3.5.3 Coax Cable Lengths and Losses

Use coax RG-223, 50 Ohm, for RF connections between MRU and DAS antennas.

Note: The required distance between the antennas (installed in the ceiling) depends on the infrastructure and calculated path loss. For example, if there is free space-loss between the antennas, a minimum distance of 100 ft is required; if there are partitions (loss) between the antennas, a distance of less than 100 ft between them is allowed.

- Observe the general cable installation procedures that meet with the building codes in your area. The building code requires that all cabling be installed above ceiling level (where applicable). The length of cable from the risers to each antenna must be concealed above the ceiling.

Coax Length	Coax Loss (900 MHz)	Connector Loss	Total Loss
30	0.7	1.5	2.2
40	0.9	1.5	2.4
50	1.1	1.5	2.6
60	1.3	1.5	2.8
70	1.5	1.5	3
80	1.7	1.5	3.2
90	1.9	1.5	3.4
100	2.1	1.5	3.6
110	2.3	1.5	3.8
120	2.5	1.5	4
130	2.7	1.5	4.2
140	2.9	1.5	4.4
150	3.1	1.5	4.6
160	3.3	1.5	4.8
170	3.5	1.5	5
180	3.7	1.5	5.2
190	3.9	1.5	5.4
200	4.1	1.5	5.6

Table 3-1. Description of Coax Length and Losses

3.6 Antenna Specifications and Guidelines

Determine the antenna installation configuration according to the transmission and coverage requirements and the installation site conditions.

3.6.1 Authorized Antennas and Required Specifications

- External antennas – no limitation on any vendor of available external antennas with respect to the following requirements:
- Omnidirectional or directional, Supported frequency range: wideband antennas supporting a range of 700 to 2600 MHz, Gain: up to 12.5 dBi, Impedance: 50 Ohm.
- Couplers – use N-male to N-female broadband coupler separately ordered from Corning (P/N AK-1COUPLER-NM-NF) or the equivalent:
- Broadband frequency: 300-3000 MHz, -20 dB coupling (SMA coupling port), Maximum VSWR/return loss: 12 dB, Maximum insertion loss: 0.2 dB
- Number of antennas that can be connected (with cables/splitters) – it is not recommended to connect more than one antenna per connector since 1:1 connectivity is reduced with each split.
- Types of couplers/splitters – depends on number of splits (not recommended).

3.6.2 General Installation Guidelines

- The MRU should be installed at a convenient location, free of metallic obstruction (can also be installed in plenum spaces).
- Install the MRU at the designated height and tune it roughly toward the service coverage area.
- Installation of this antenna must provide a minimum separation distance of 100 cm from any personnel within the area.
- Cable and jumper loss is at least 2 dB.

3.7 Fiber Optic Requirements

3.7.1 Authorized Optical Cables

The following specified optical cables are authorized for use with the MRU product:

- Composite plenum tether assemblies
- Fiber: LC APC, 2-24 fibers
- cu: 16, 14, 12 AWG; 2-12 conductors
- Armored, non-armored

3.7.2 Fiber Optic Rules

- Use only LC APC connectors.
- UniCam[®] connectors can be used for field termination.
- Use only fusion splice for connecting two fibers.
- Use minimum splicing/connectors to achieve minimum losses on the fibers (< 0.5 dB).
- Use precaution while installing, bending, or connecting fiber optic cables:
 - Fiber optic cable is sensitive to excessive pulling, bending, and crushing forces. Consult the cable specification sheet for the cable you are installing.
 - Do not bend cable more sharply than the minimum recommended bend radius.
 - Do not apply more pulling force to the cable than specified.
 - Do not crush the cable or allow it to kink. Doing so may cause damage that can alter the transmission characteristics of the cable. The cable may have to be replaced.
- Use an optical power meter and light source for checking the fiber optic cables.
- Make sure the environment is clean while connecting/splicing fiber optic cables.
- All fiber optic connectors should be cleaned prior to connecting to the system.

- Fiber connector protective caps should be installed on all non-terminated fibers and removed just before they are terminated.
- Pay special attention while connecting the LC APC connectors – ensure that you hear a “click,” indicating a secure connection.
- Never look directly into the end of a fiber that may be carrying laser light. Laser light can be invisible and can damage your eyes.

3.8 Grounding Requirement

Verify that the equipment has been well grounded (refer to the grounding lug on the bottom front panel of the MRU chassis). This requirement includes antennas and all cables connected to the system. Ensure lightning protection for the antennas is properly grounded. See Section 4.3 for MRU grounding connection.

3.9 Manual Handling

During transportation and installation, take necessary handling precautions to avoid potential physical injury to the installation personnel and the equipment.

Installation

CHAPTER 4

This document describes the installation procedure for the Corning optical network evolution (ONE™) solutions mid-power remote unit (MRU). Please refer to Chapter 3 – Installation Guidelines for specific guidelines on infrastructure planning, design, and installation or consult with a Corning product line manager or Corning-approved installer.

4.1 Unpacking and Inspection

Unpack and inspect the cartons as follows:

1. Open the shipping cartons and carefully unpack each unit from the protective packing material.
2. Verify that all the items listed in Table 4-1 are included in the MRU package. If any of the listed items are missing, contact your Corning representative.
3. Check for signs of external damage. If there is any damage, call your Corning representative.


Kit	Item Description		Quantity	Image
MRU	Mid-Power Remote Unit <i>Note: See "Appendix B: Ordering Information" for MRU part numbers.</i>		1	
	Hosted Modules (pre-installed)*	Service-Specific Power Amplifier Modules (PAM) – pre-installed according to ordered configuration	1-5	
		Fan Module (FAM)	1	
		AC or DC (model dependent) Power Supply Module (PSM)	1	
	AC Power Cable (AC models only)	Power Cable, straight, U.S., 10 A, UL, L = 1.8-2.5 m, black, 110 V	1	
	Rack Ears for 19-in rack (factory assembled onto sides of MRU)		2	

Table 4-1. MRU Kits

** ATTENTION! In the event that a PAM or the OPTM needs to be removed from the chassis, make sure to first press the release button on the module and then pull out using the handle. Any attempt to pull out the module without first releasing may cause damage. Refer to Section 5.1 for more details. Corning will not be liable for damage of products resulting from improper handling during installation or repair.*

4.2 Mounting the MRU

The MRU supports two types of mounting installations:

- 19-in rack installation (Section 4.2.1)
- Wall-mount installation (Section 4.2.2)
- Outdoor installation – the MRU can be installed in a separately ordered outdoor enclosure; Refer to Section 4.2.3 for instructions on how to install the MRU in a Purcell Systems cabinet (FlexSure® 12-2420).

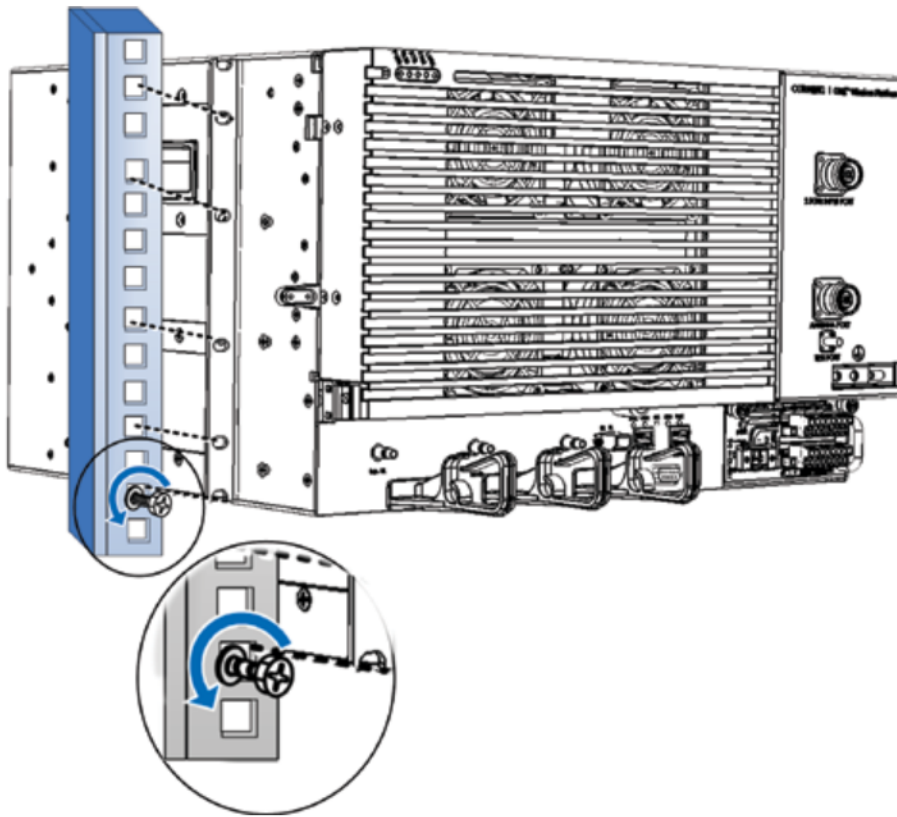
4.2.1 Rack Installation

Note the following:

- MRU chassis requires 6U rack height availability.
- Rack nuts and screws not provided.

To install MRU in rack

1. Determine the location of the MRU in the rack while considering additional units (e.g. power supply).
2. Referring to Figure 4-1, secure the units' rack ears to the rack frame as follows:
 - Insert two screws halfway into the rack frame (one on each side).
 - Position the bottom half slots of the chassis rack ears on to the screws.
 - Secure the unit in the rack via the three remaining applicable bracket holes using the appropriate rack nuts and screws.



Example of MRU Chassis Rack Installation | Figure 4-1

4.2.2 Wall-Mount Installation

Note the following:

- MRU wall-mount brackets are not included with the MRU package and are ordered separately (P/N: BR-MRU-W).
- The mounting surface shall be capable of supporting the weight of the equipment. The weight of a fully populated MRU chassis is 70.55 lbs (32 kg).
- The installer is responsible for accommodating the installation to the surface type.

4.2.2.1 Unpacking and Inspection

Unpack and inspect the carton as follows:

1. Open the shipping carton and carefully unpack each unit from the protective packing material.
2. Verify that all the items listed in Table 4-2 are included in the wall-mount bracket package. If any of the listed items are missing, contact your Corning representative.
3. Check for signs of external damage. If there is any damage, call your Corning representative.



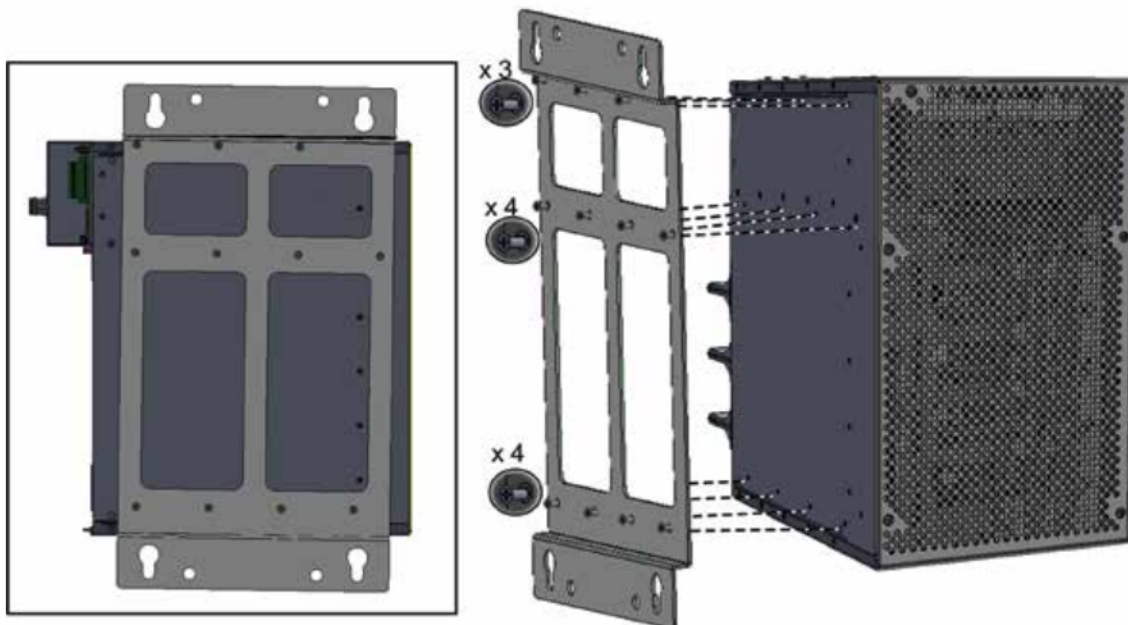
Item	Quantity	Image
Wall-Mount Bracket	1	
Screws, flat head, 8-32 x 3/8	11	

Table 4-2. MRU Wall-Mount Bracket Package Items

4.2.2.2 Mounting MRU on Wall

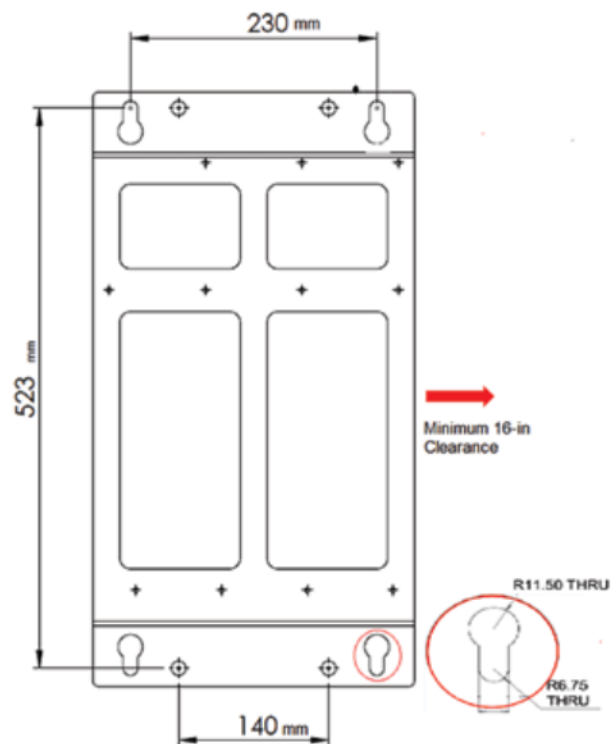
1. Assemble wall-mount bracket to MRU underside.



Assembling Bracket onto MRU | Figure 4-2

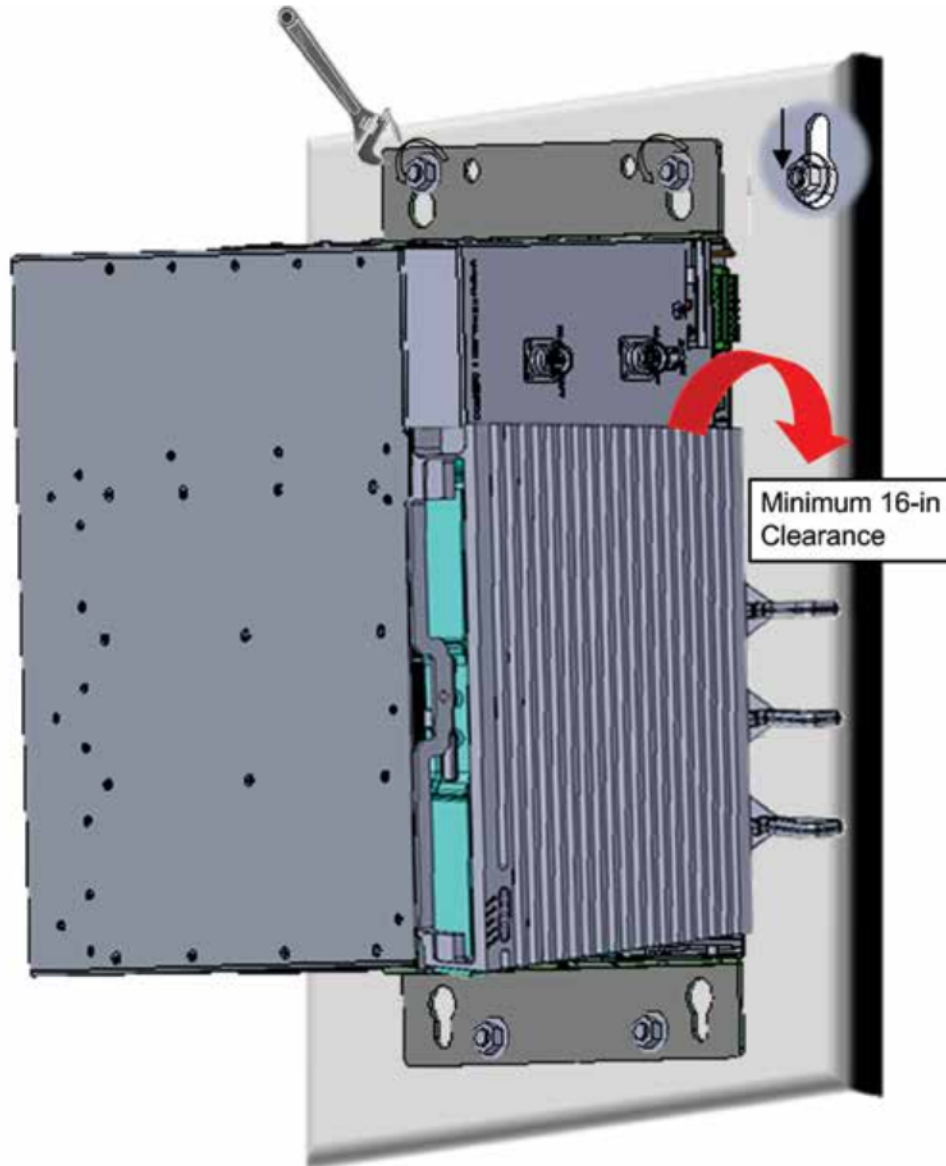
2. Select location and mark and drill appropriate holes in wall.

⚠ IMPORTANT! MRU is installed belly-to-the-wall with door opening rightward. If installed near a right facing wall, make sure that there is at least 16 in of clearance to open the door to the right and to successfully remove and replace all modules.



Wall-Mount Bracket Dimensions | Figure 4-3

2. Insert anchors in wall, hang unit, and tighten to secure.



Mounting MRU on Wall | Figure 4-4

4.3 Grounding MRU Chassis

The grounding connection is performed via a two-hole, standard barrel grounding lug located on the front of the MRU chassis (see Figure 4-5).

Required tools and components

The following additional (not supplied) tools and components are required for connecting the system ground:

- Grounding wire – The grounding wire should be sized according to local and national installation requirements. The provided grounding lug supports 14 to 10 AWG stranded copper (or 12 to 10 AWG solid) wire conductors.

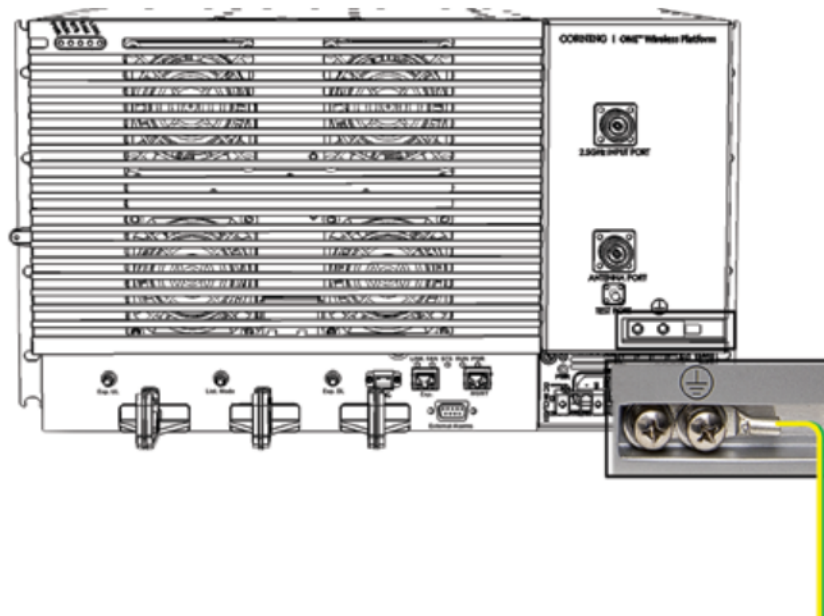
Note: The length of the grounding wire depends on the proximity of the switch to proper grounding facilities.

- Phillips screwdriver.
- Crimping tool to crimp the grounding wire to the grounding lug.

- Wire-stripping tool to remove the insulation from the grounding wire.

Connecting system ground

1. Use a wire-stripping tool to remove approximately 0.4 in (10.9 mm) of the covering from the end of the grounding wire.
2. Insert the stripped end of the grounding wire into the open end of the grounding lug.
3. Crimp the grounding wire in the barrel of the grounding lug. Verify that the ground wire is securely attached to the ground lug by holding the ground lug and gently pulling on the ground wire.
4. Prepare the other end of the grounding wire and connect it to an appropriate grounding point at the site to ensure adequate earth ground.

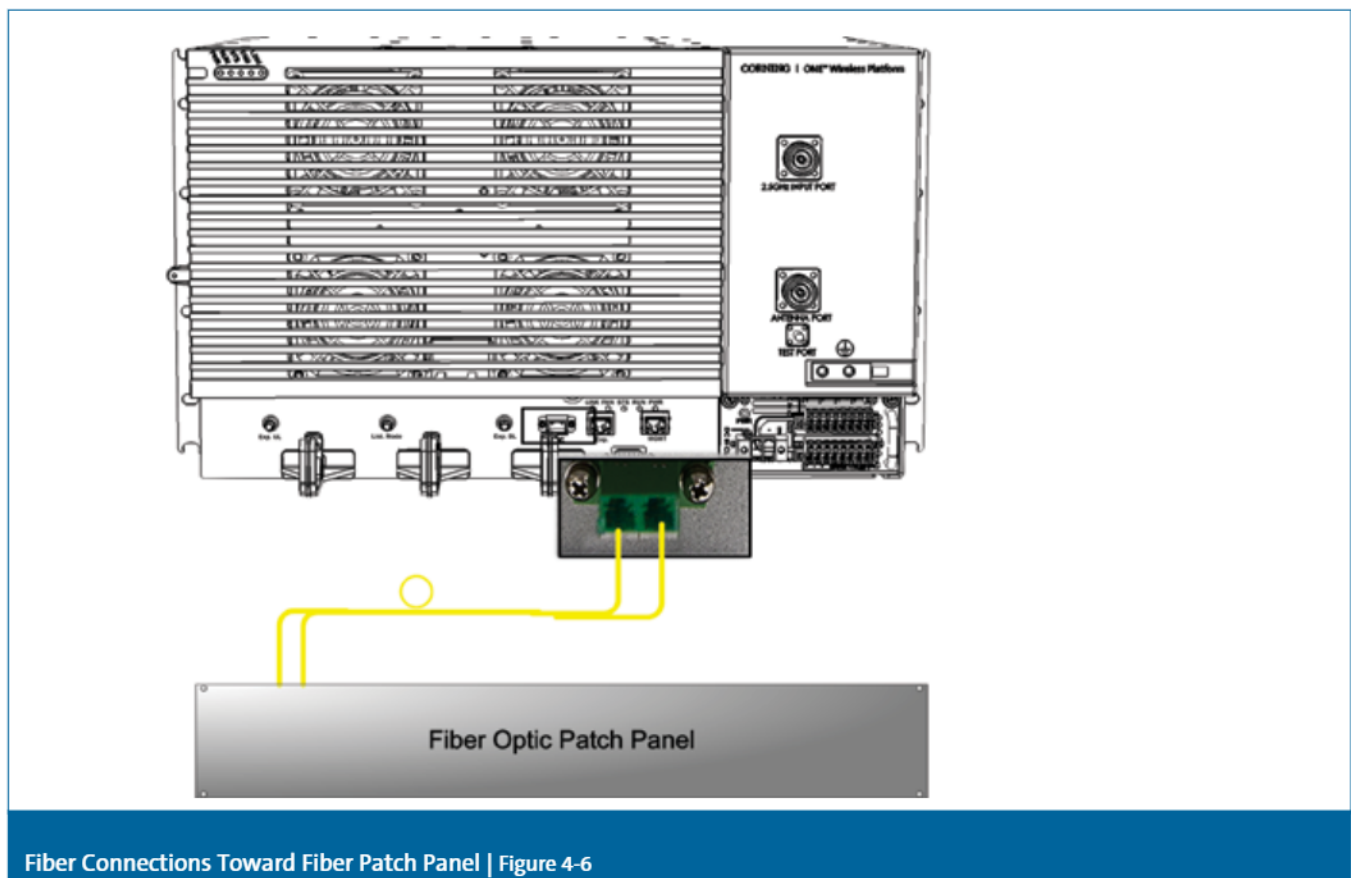


MRU Grounding Lug Connection | Figure 4-5

4.4 Fiber Connections

To connect optical fiber

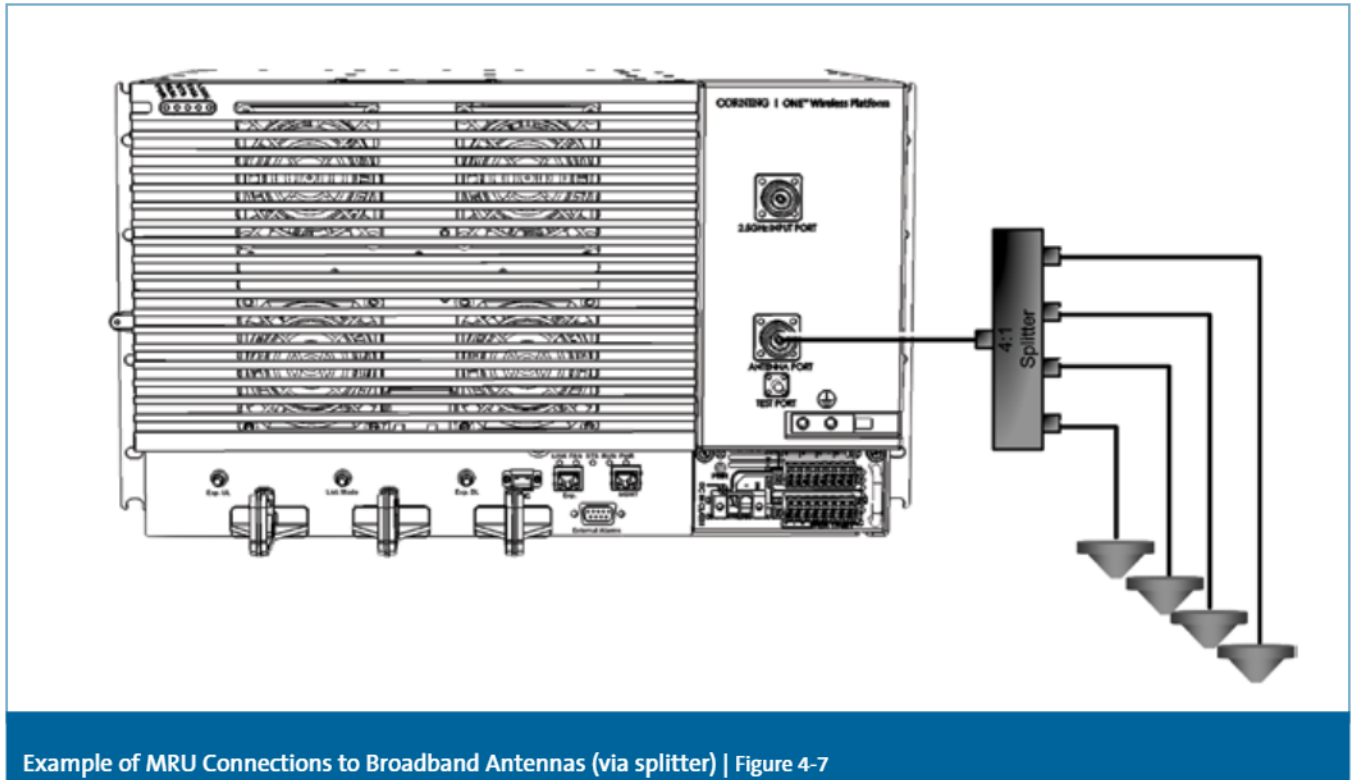
1. Remove the LC APC connector plugs.
2. Using Corning® SMF-28® fiber (or compatible), connect the MRU LC APC fiber connector to the fiber patch panel. See Figure 4-6.



4.5 RF Antenna Connections

Connect the MRU male DIN type 4.3-10 duplexed RF “ANTENNA” port to the broadband antenna(s) using appropriate coax cables. See Figure 4-7.

The MRU includes one 4.3-10 type RF port used for connecting to a 2.5 GHz external RF source (e.g. picocell).



4.6 Power Connections

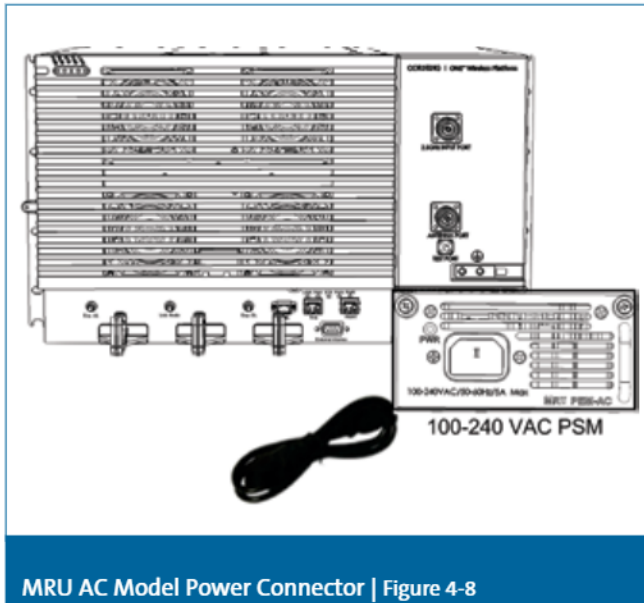
The MRU power connections depend on the type of power module (AC or DC). The PSM is located on the bottom right of the chassis front.

- Refer to Section 4.6.1 for AC model power connections
- Refer to Section 4.6.2 for DC model power connections

4.6.1 AC Models

Using the provided AC power cable only, simply connect the MRU AC power connector to the AC power source. Note the following:

- Power input: 100-240 VAC/50-60 Hz
- Power consumption: 360 W (maximum)
- Maximum AC current consumption: 5 A



MRU AC Model Power Connector | Figure 4-8

4.6.2 DC Models

DC models include two types of terminal block connectors:

- CLASS2 (default) – two 8-pin terminal block connectors for remote feed (see Section 4.6.2.1).
- CLASS1 – one 2-pin terminal block for local plant feed. To use CLASS1, user must change default connector mode from CLASS2 to CLASS1 (see Section 4.6.2.2).

4.6.2.1 CLASS2 Connector (remote feed)

The CLASS2 DC connector supports one pair for each installed PAM (up to five pairs), one pair for OPTM and FAM, and one reserved pair (RSV) for future use. Refer to Figure 4-9.

DC CLASS2 connector specs:

- Supported wire AWG:
 - Conductor cross-section, solid (AWG/mm²): 30-12/0.2-2.5
 - Conductor cross-section, flexible (AWG/mm²): 30-12/0.2-2.5
- Wire strip length: 9-10 mm
- DC power input:
 - DC class 1: 48 VDC (40-60 VDC) 9 A maximum
 - DC class 2: 24/48 VDC (20-60 VDC) 1.75 A maximum per pair
 - Power amplifier consumption per pair: 50 W
- Maximum power consumption: 330 W
- Maximum current consumption: 1.75 A per pair

To perform CLASS2 DC connector wiring – for each DC pair:

1. Identify the positive and negative terminals for the DC pair to be wired on the CLASS2 connector feed positions. The wiring sequence is positive to positive and negative to negative as shown in Figure 4-9.
2. Use a wire-stripping tool to remove the covering from the end of the DC wire pairs.

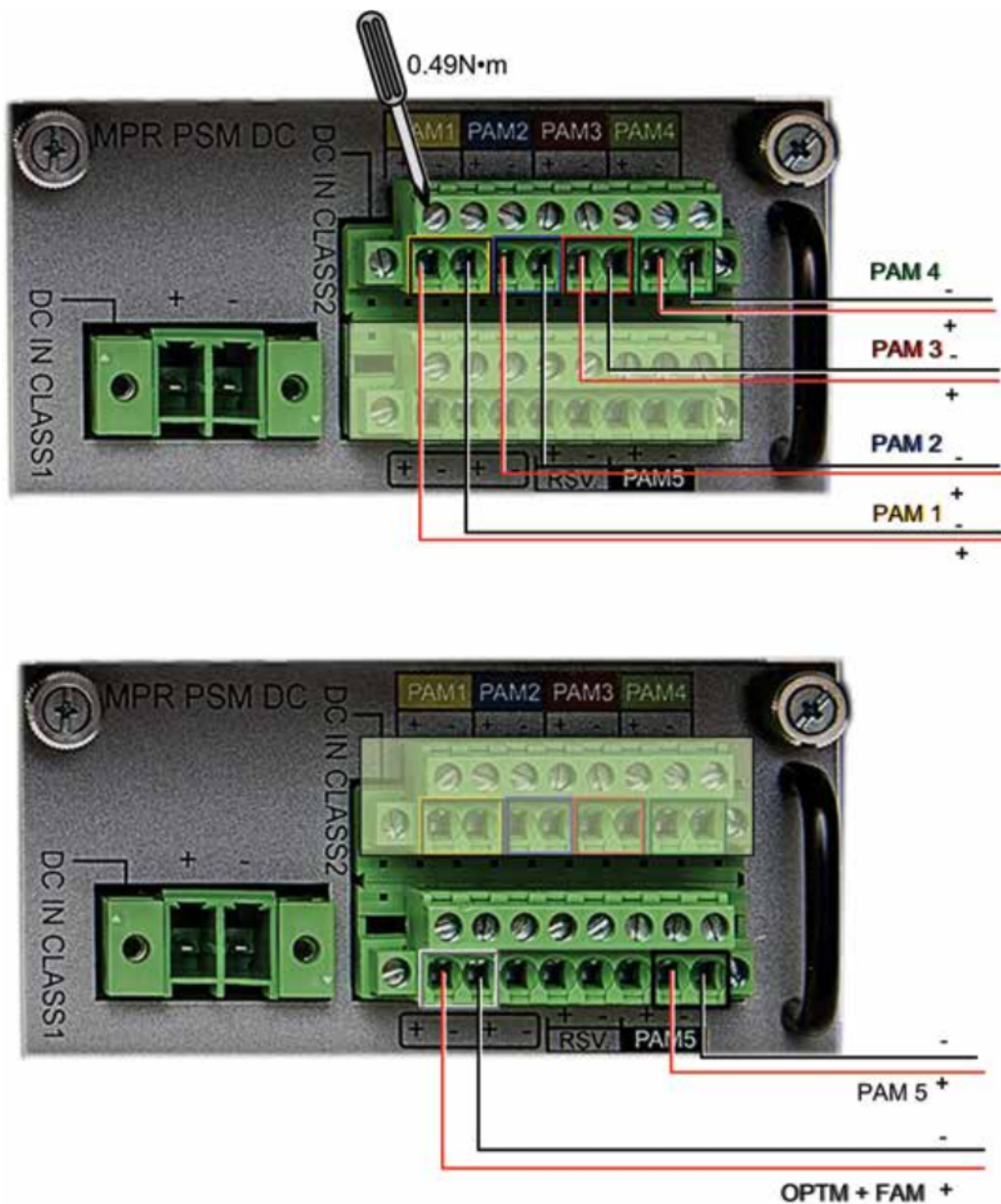
3. Open the terminal block screw above the negative feed position and then insert the exposed black wire (negative feed) into the terminal block.

Note: Ensure that no exposed portion of the DC wires extends from the terminal block plug.

4. Torque the terminal block captive screw (above the installed wire lead), using a ratcheting torque screwdriver. Recommended torque is $0.49 \text{ N}\cdot\text{m}$.

5. Repeat the same process as in Steps 3 and 4 for remaining positive feed (exposed red wire).

⚠ CAUTION! Secure the wires coming in from the terminal block so that they cannot be disturbed by casual contact. For example, use tie wraps to secure the wires to the rack.



Example of CLASS2 DC Wiring Connections | Figure 4-9

4.6.2.2 CLASS1 Connector (local plant feed)

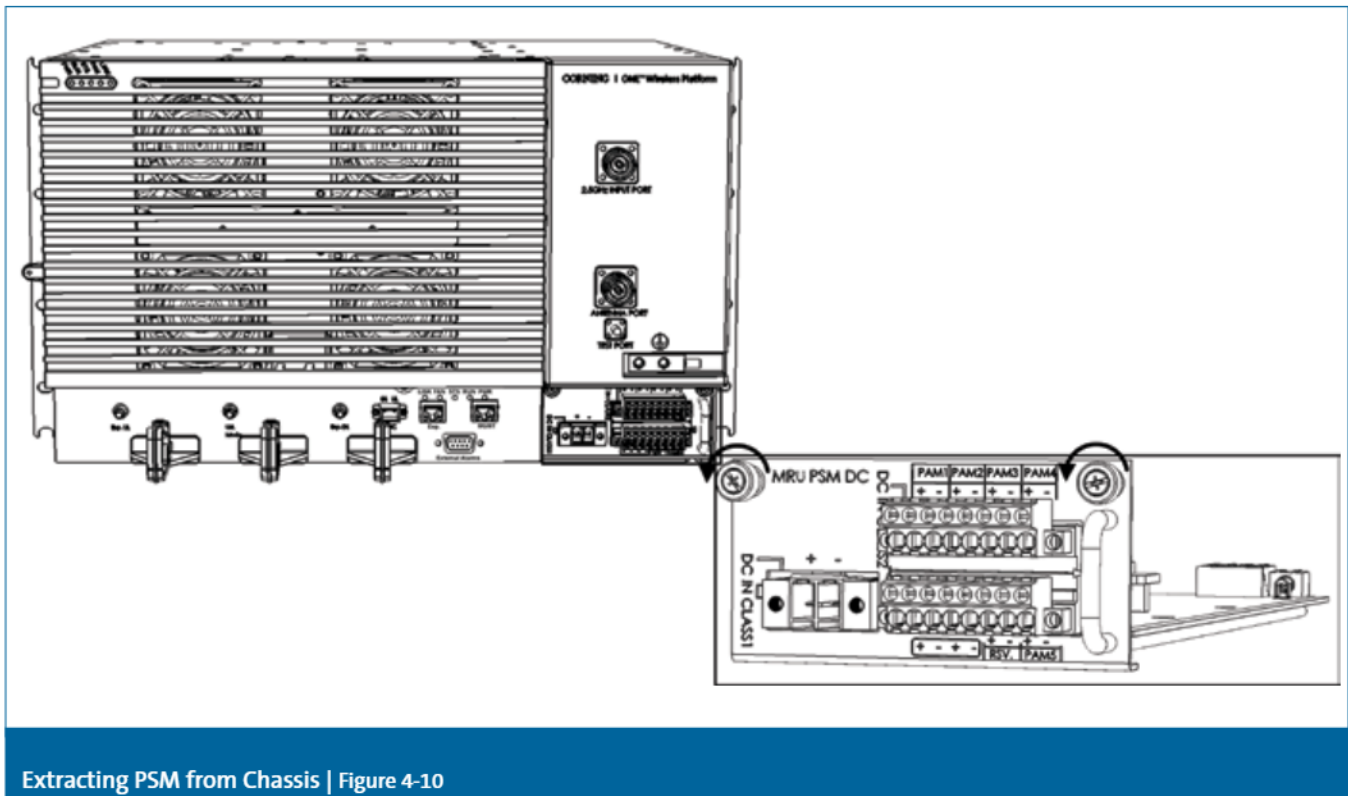
Note: In order to power the MRU via the CLASS1 connector (two-pole terminal plug), the DC bridge must be moved from the default CLASS2 mode position to CLASS1.

DC CLASS1 power specs:

- Power input: 48 VDC (40-60 VDC)
- Maximum current consumption: 9 A

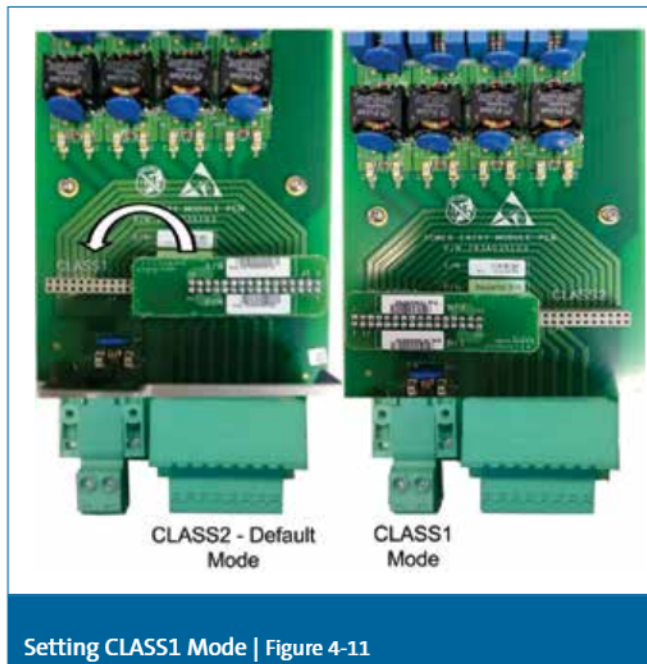
To perform CLASS1 DC connector wiring

1. Loosen PEM captive screws and pull out module from chassis. See Figure 4-10.



Extracting PSM from Chassis | Figure 4-10

2. Move DC bridge from CLASS2 position to CLASS1 to set DC input source type to “CLASS1” connector. Refer to Figure 4-11.



3. Push PSM back in slot and close captive screws.
4. Identify the positive and negative terminals for the DC pair to be wired on the CLASS1 connector feed positions. The wiring sequence is positive to positive and negative to negative.
5. Use a wire-stripping tool to remove the covering from the end of the DC wire pairs.
6. Open the terminal block screw above the negative feed position and then insert the exposed black wire (negative feed) into the terminal block.

Note: Ensure that no exposed portion of the DC wires extends from the terminal block plug.

7. Torque the terminal block captive screw (above the installed wire lead), using a ratcheting torque screwdriver. Recommended torque is 0.49 N•m.
8. Repeat the same process as in Steps 6 and 7 for remaining positive feed (exposed red wire).

⚠ CAUTION! Secure the wires coming in from the terminal block so that they cannot be disturbed by casual contact. For example, use tie wraps to secure the wires to the rack.

4.7 Outdoor Installation

This section provides instructions on how to install the MRU in a Purcell Systems cabinet (FlexSure 12-2420) and perform external alarm connections between the unit and the enclosure.

Note the following:

- The MRU, outdoor enclosure, and required dry contact alarms cable are each ordered separately.
- Additional relevant documentation – Purcell Systems FlexSure® 12-2420 installation manual provided with the cabinet.
- Only trained and qualified personnel should be allowed to install, replace, or service this equipment.
- The MRU connections are performed after the chassis is installed in cabinet.

4.7.1 Items Required for Outdoor Installation

Refer to Table 4-3 for the items required for installing the MRU in the outdoor enclosure.

Kit	Item	Quantity
FLX12-2420 Enclosure	Purcell Systems FlexSure® 12U Outdoor GR-487 Enclosure for single MRU installations in SISO cabinets: Purcell Systems P/N: 2000003905 FLX12-2420, 39W/C HEX, right hinge door Purcell Systems P/N: 2000003974 FLX12-2420, 39W/C HEX, left hinge door	1
MRU	Mid-Power Remote Unit	1
FLX12-2420 Pole-Mounting Kit (optional)	P/N 2000003986 Platform Pole-Mount Kit for FLX12-2420 SISO and FLX16-2520 MIMO	1
FLX12-2420 Wall-Mounting Kit (optional)	P/N 2000003985 Wall-Mount Kit for FLX12-2420 SISO	1
External Alarms Cable (AK-MRU-DCA-CBL)	DB9 Male Open Wire Cable for external alarm connections	1

Table 4-3. Items Required for Outdoor Installation

Additional required items (not provided):

- Standard electrician tools (including ratchet wrench with extension bar and 8 mm socket) for tightening self-drilling screws securing MRU chassis to cabinet rails)
- Assorted cable ties
- 90-degree right angle 4.3-10 type male connector coax cables – one for antenna connection and one for external 2.5 GHz RF source connection (if relevant)
- Recommended – flexible cable conduits for routing connections cables through cabinet knockouts; refer to Figure 4-6 for relevant knockouts. Following are recommended Heyco part numbers for flexible conduits:

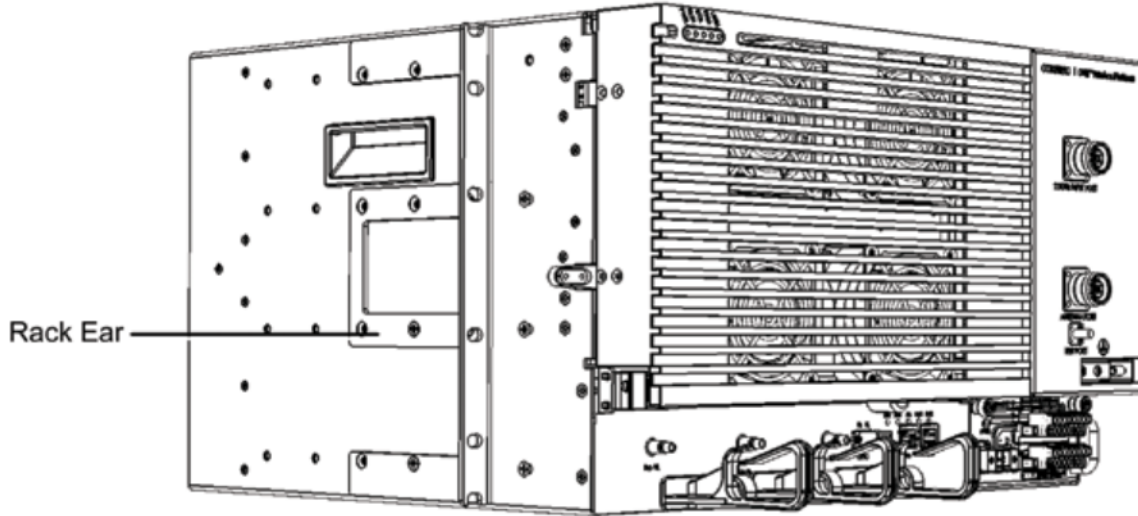
Manufacturer P/N	Description
8406	HFC 1 Conduit Fitting with 8467 nut, 1-in thread, black
8453	HF2 1 Tubing, 100-ft coil, black
8456	HFC 2 Tubing, 50-ft coil, black
8642	HFC 2 Conduit Fitting, 2-in thread, black

Table 4-4. Recommended Conduits

- Sealing material for knockouts – if not using conduits

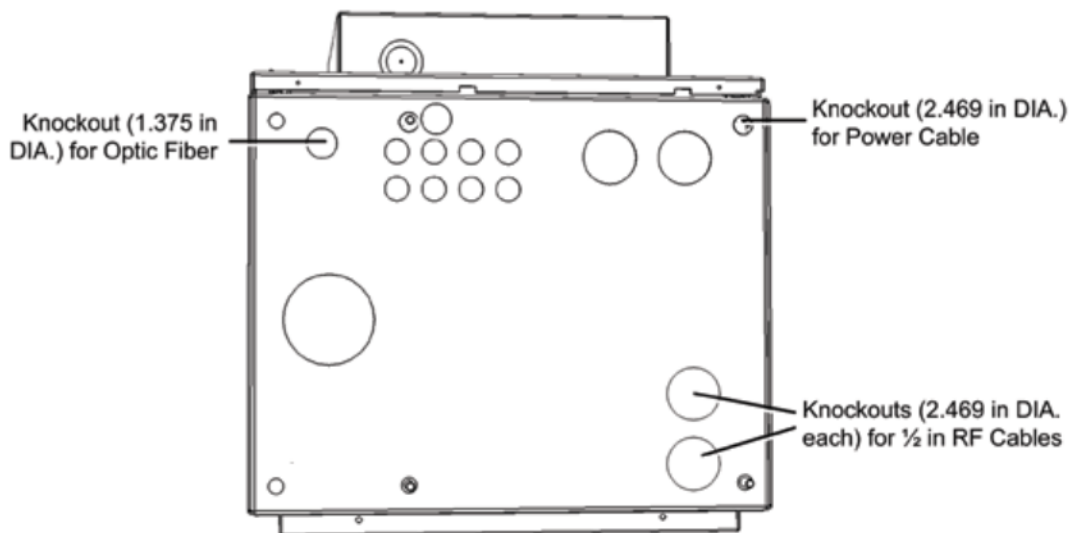
4.7.2 Pre-Installation Procedures

1. Remove each rack ear and reassemble according to position shown in Figure 4-12.



Required Position of MRU Rack Ears | Figure 4-12

2. Referring to Figure 4-13 for relevant knockouts, use appropriate knockout tools to punch out knockouts for routing connection cables.



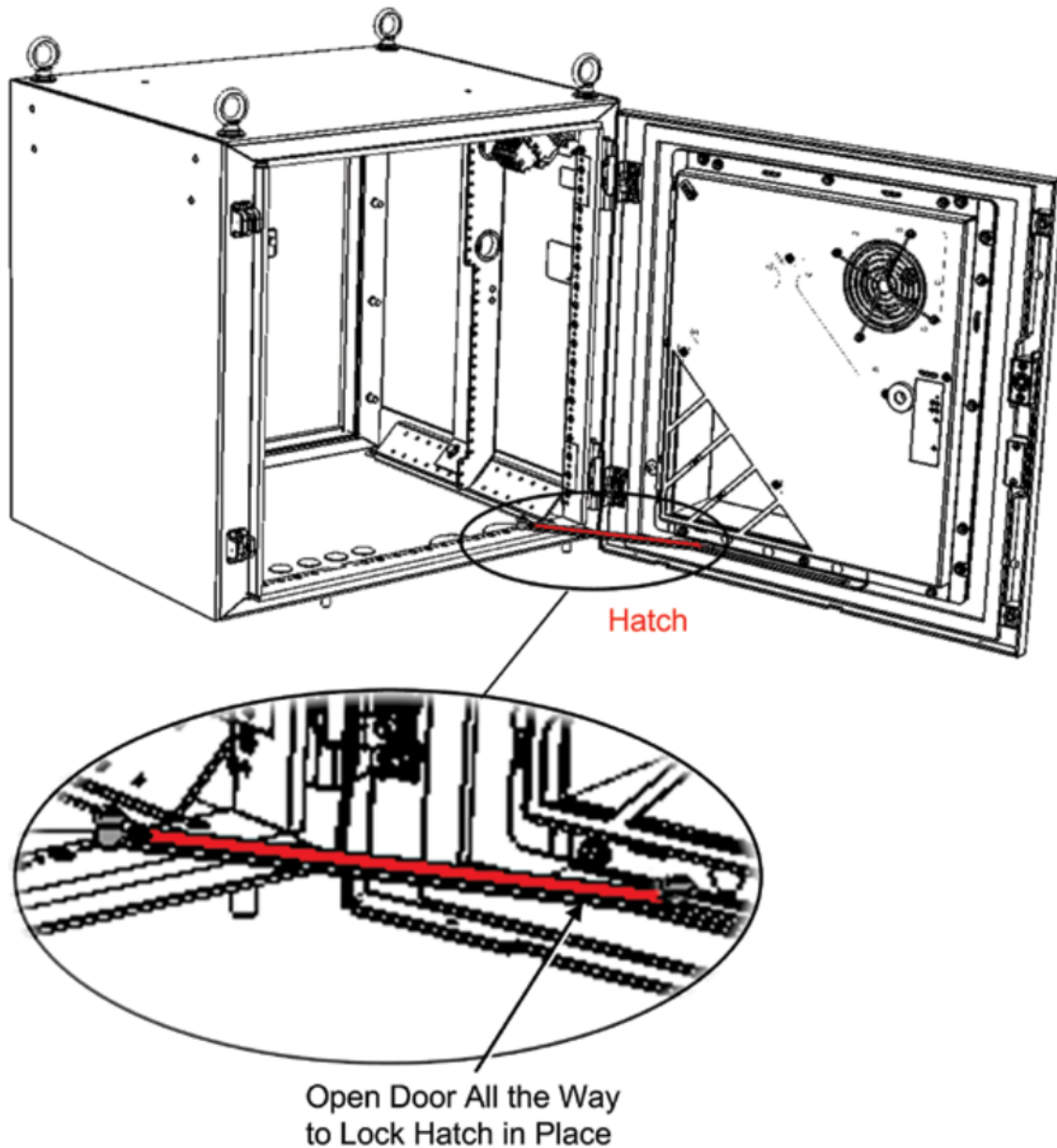
Required Knockout Positions | Figure 4-13

4.7.3 Install MRU in Cabinet

1. Carefully lay cabinet on backside (so door faces upward) and open door.

⚠ ATTENTION! Make sure that the door hatch locks into the door rail in order to avoid closing of door while installing the chassis. See Figure 4-14.

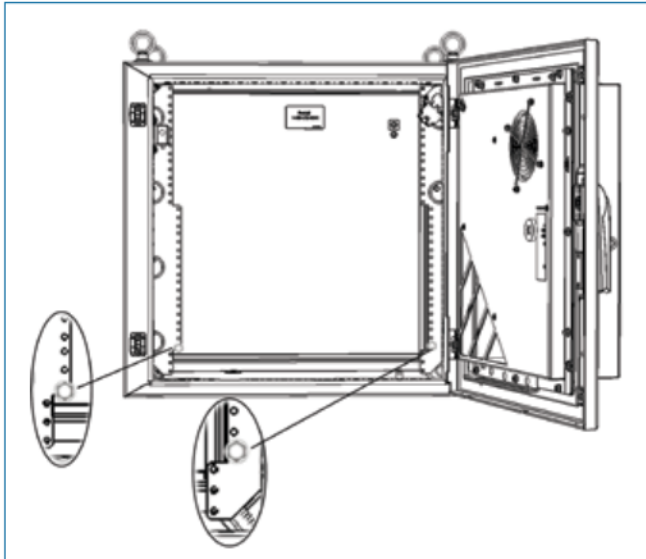
Note: Push hatch inward toward the door to release and close the cabinet.



Opening Cabinet Door and Locking in Place | Figure 4-14

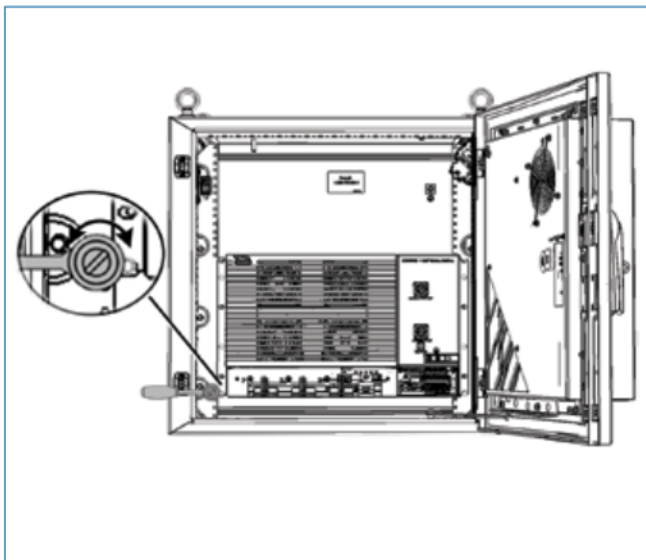
2. Insert one 8-mm self-tapping screw (provided with the cabinet) halfway into the bottom hole of each rail. Refer to Figure 4-15.

Note: An extension bar may be required to access the screws due to narrow space between chassis and cabinet rails.



Self-Tapping Screw Inserted in Each Rail | Figure 4-15

3. Position the bottom half slots of the MRU rack ears onto the protruding screws and tighten the screws using a ratchet wrench. Refer to Figure 4-16.



Securing MRU to Cabinet Rails | Figure 4-16

4. Insert at least two additional screws into each of the cabinet rails to safely secure MRU and tighten.

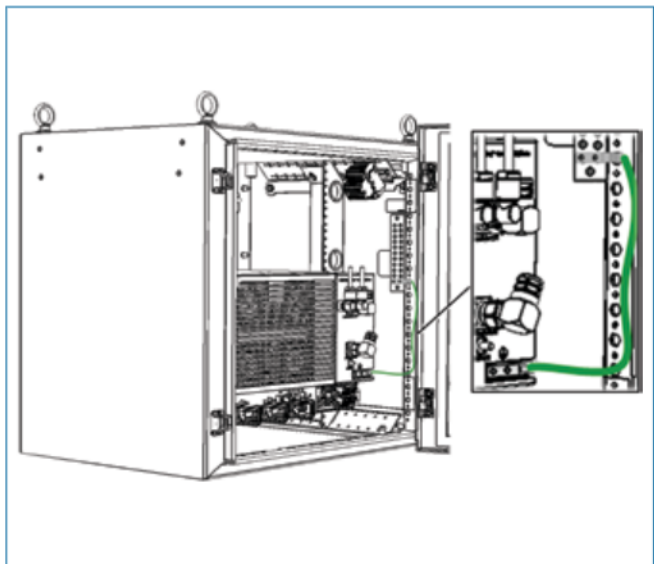
5. (Optional) Insert the appropriate conduits (refer to Table 4-4 in Section 4.7.1 for recommended part numbers) in each of the punched out knockouts.

4.7.4 MRU Connections

Note the following:

1. Ground the cabinet and MRU:

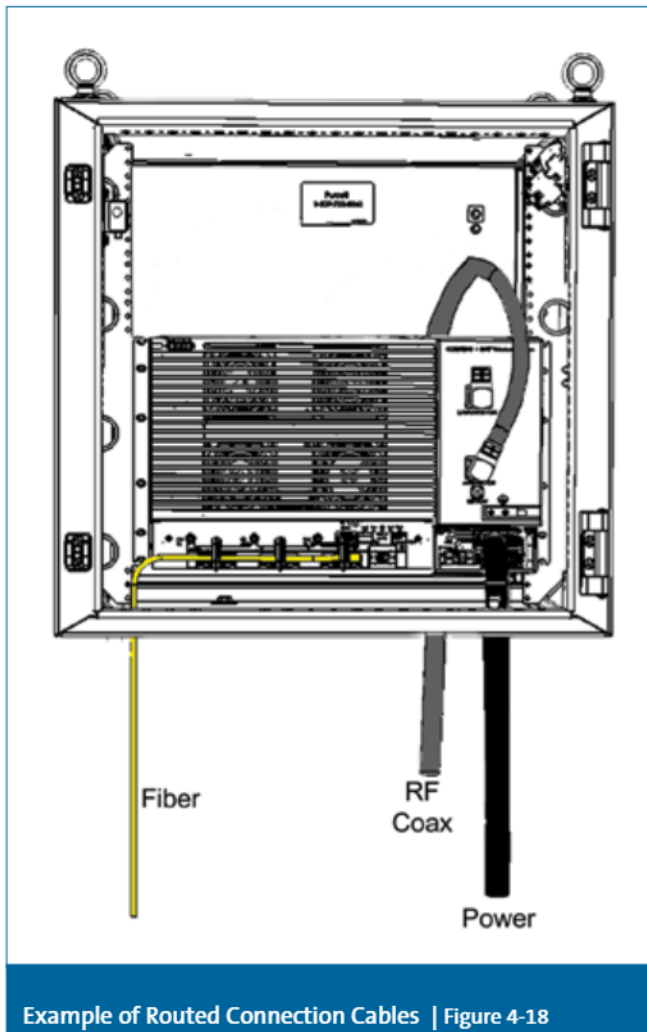
- For cabinet grounding instructions – refer to the manufacturer's installation guide for instructions on cabinet grounding.
- Using one of the grounding cables provided with the cabinet, ground the MRU chassis via the two-hole, standard barrel grounding lug located on the front panel to one of the cabinet grounding bolts. Refer to Figure 4-17.



Grounding MRU to Cabinet | Figure 4-17

2. Connect RF antenna coax – (for both 4.3-10 type “ANTENNA PORT” and “2.5 GHz INPUT PORT”) route coax cable with 90-degree right angle connector through its designated knockout (see Figure 4-13) behind and above the MRU chassis and connect to the corresponding RF port. Refer to Figure 4-18.
3. Route optical fiber from ICU and power cable through designated knockouts (see Figure 4-13) and connect according to instructions in Section 4.4. Refer to Figure 4-18.

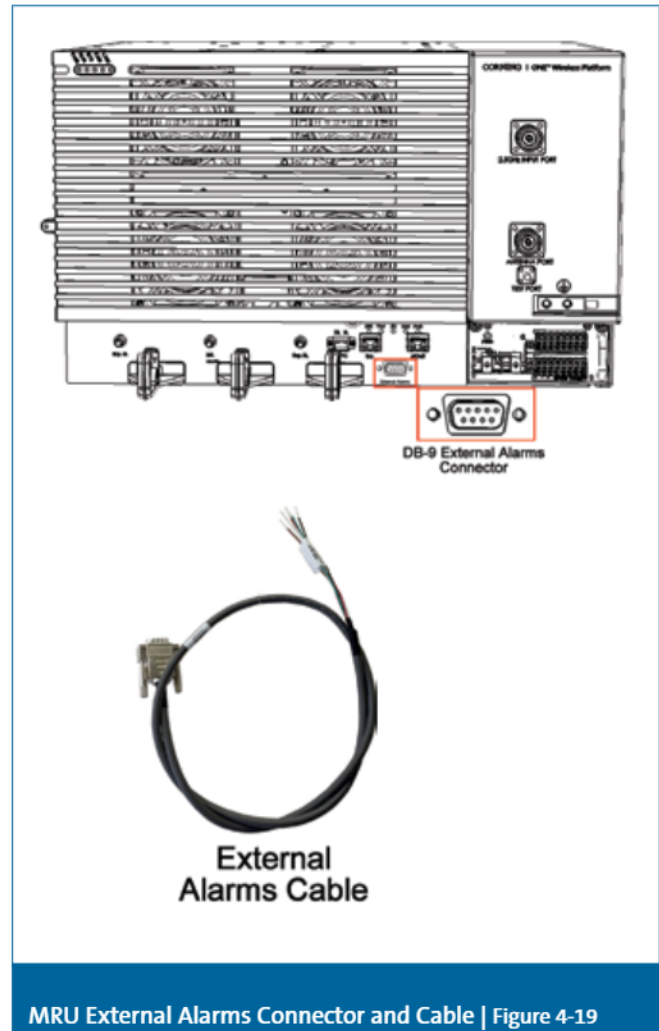
Note: For DC power connections – route DC power cable with open wires (without connector) and then wire according to instructions in Section 4.6.2.



4.7.5 External Alarm Connections

Note: Also refer to relevant section of the Purcell Systems cabinet installation manual (i.e. “Connecting Optional Custom Alarms”).

A DB9 female pin “External Alarms” connector (located on optical module below RJ45 ports) provides support for up to three external dry contact alarm connections from external sources (incoming outputs). See Figure 4-19. The connector provides indications for door opening, heat exchanger (HEX) and one additional input for future use.

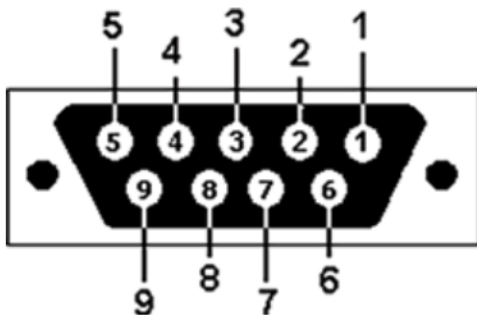


To perform external alarm connections:

1. Connect the external alarms cable (ordered separately) to the chassis's DB9 "External Alarms" connector. Refer to Table 4-5 and Figure 4-20 for pinout information.

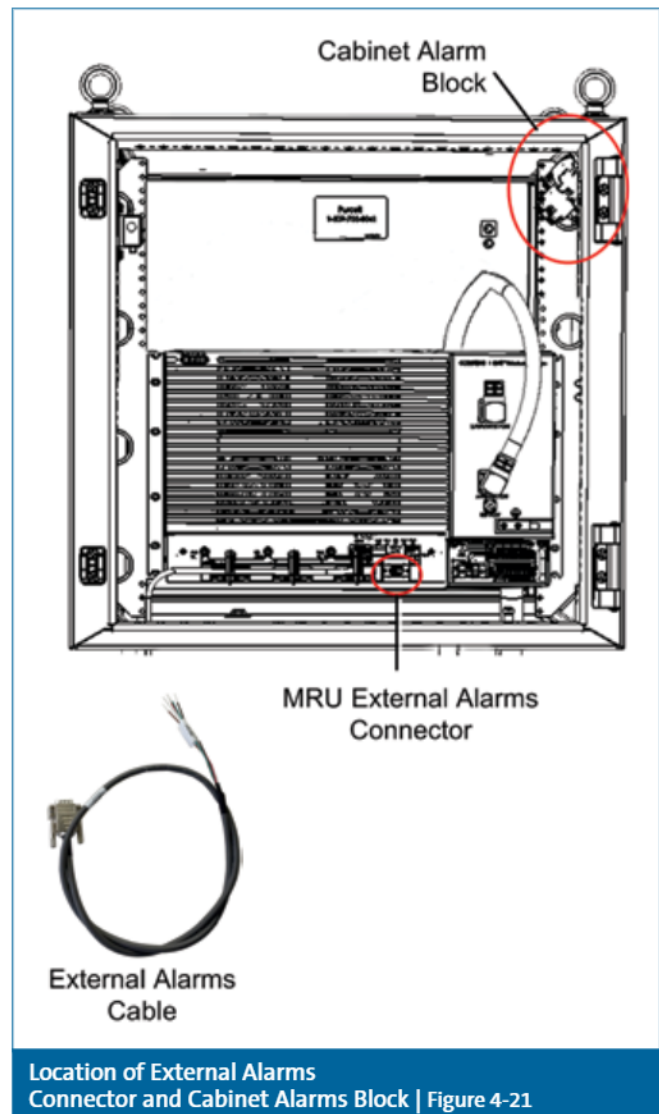
Pin	Description
1	Common
2	Not connected
3	Not connected
4	Not connected
5	Not connected
6	Door alarm
7	Heat exchange (HEX) alarm
8	Future alarm
9	Exist indication (indicates existing connection of alarm cable)

Table 4-5. MRU External Alarm Connector Pinout Description



MRU External Alarms Connector Pinout | Figure 4-20

2. Route the cable alarm wires to the alarm block, located on the upper right corner of the cabinet. See Figure 4-21.



3. Connect the external alarm connections to the cabinet. Table 4-6 provides the dry contact alarms cable wiring description.

Color	Description
Red	+48 V_COMMON
Green	-48 V_EXIST INDICATION
Brown	-48 V_DOOR ALARM
Black	-48 V_HEX ALARM
White	-48 V_FUTURE ALARM

Table 4-6. Dry Contact Alarm Cable Wiring Info

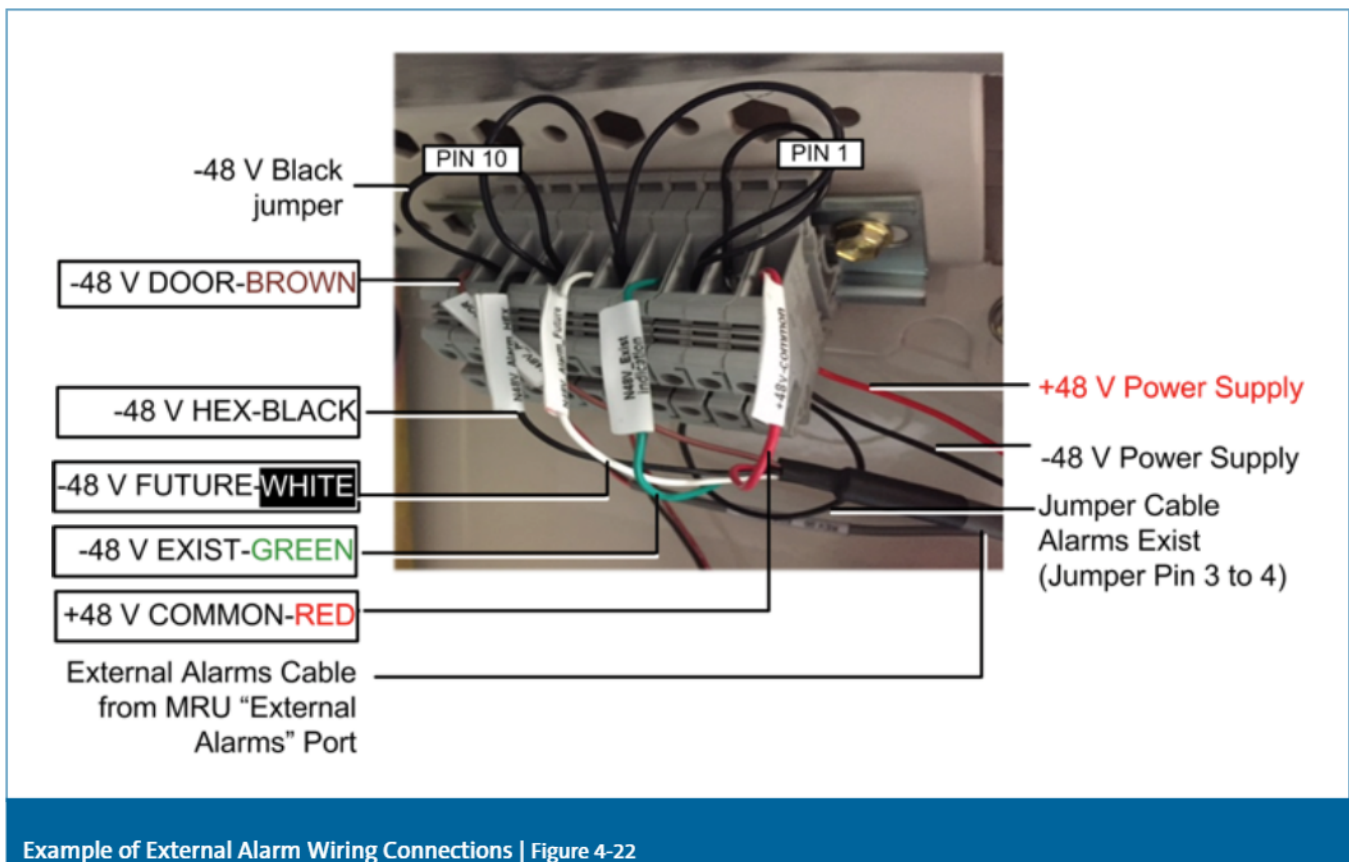
Refer to Table 4-7 for wiring description of MRU External Alarms connector and to Figure 4-22 for examples of the upper and lower cabinet block wiring connections.

External Alarms Connector Pin No.	
1	Common
6	Door Alarm
2	NC
7	HEX Alarm
3	NC
8	Future Alarm
4	NC
9	Exist Indication
5	NC (not connected)

Table 4-7. External Alarms to Cabinet Block Wiring

4.8 Verifying Normal Operation

- Verify that all the fans are operational.
- By referring to Table 2-2 in Chapter 2, verify that all the LEDs on the top-left of the chassis door and on each PAM are signaling normal system operation.



4. Verify that fans are operational. Refer to status LEDs on the inside of the cabinet door and verify that all show green.

Maintenance

All of the MRU components (except backplanes) are hot swappable and field upgradable modules (i.e. PSM, PAM, OPTM, and FAM). Refer to Chapter 7 - Appendix B: Ordering Information for stand-alone modules which can be ordered for upgrade or maintenance purposes.

5.1 Extracting/Replacing PAM and OPTM

⚠ ATTENTION! In the event that a PAM or the OPTM needs to be removed from the chassis for upgrade or maintenance purposes, make sure to first press the release button on the module and then pull out using the handle. Any attempt to pull out the module without first releasing may cause damage. Corning will not be liable for damage of products resulting from improper handling during installation or repair.



Extracting PAM/OPTM Module | Figure 5-1

Appendix A: Specifications

CHAPTER 6

Supported Services

Technology	Frequency Range (MHz)		
	Service/Band	Uplink (UL)	Downlink (DL)
LTE	700 MHz Lower ABC 700 MHz Upper C	698-716 776-787	728-746 746-757
CDMA/LTE	ESMR 800	817-824	862- 869
CDMA/GSM/LTE/UMTS	CELL 850	824-849	869-894
CDMA/LTE/GSM/UMTS	PCS + G 1900	1850-1915	1930-1995
UMTS/LTE	AWS + AWS-3	1710-1778	2110-2180
LTE	WCS	2305-2315	2350-2360
LTE	BRS/EBS	2496-2690	

RF Parameters per Service

Service/Band	LTE 700 MHz		ESMR 800/ CELL 850 MHz		AWS 1700 MHz		AWS1/3*** 1700 MHz		PCS 1900 MHz		WCS 2300 MHz	
	DL	UL	DL	UL	DL	UL	DL	UL	DL	UL	DL	UL
Frequency Range (MHz)	728-746 746-756	698-716 777-787	862-869/ 869-894	817-824/ 824-849	2110- 2155	1710- 1755	2110- 2180	1710- 1780	1930- 1995	1850- 1915	2350- 2360	2305- 2315
Maximum Output Power per Antenna Port (dBm)	30		30		33		34		33		33	
Input Power (dBm)	0-37		0-37		0-37		0-37		0-37		0-37	
UL Gain Range (dB)		-19 to 15		-19 to 15		-19 to 15		-19 to 15		-19 to 15		-19 to 15
SFDR* (dB)		60		64		60		60		64		60
Maximum Intermod Distortion (dBm)	≤ -13		≤ -13		≤ -13		≤ -13		≤ -13		≤ -13	
UL NF* (dB)		12		12		12		12		12		12
Gain Flatness/ Ripple (dB)	± 2.0		± 2.0		± 2.0		± 2.0		± 2.0		± 2.0	

*SFDR calculated with bandwidth of 1.23 MHz for the CELL and PCS and with 5 MHz for the LTE, AWS, and WCS.

**Typical for single remote unit

***AWS1/3 supported only with MRU-PAM-A17E

Coupling Specifications

DL Center Frequency of Supported Bands (MHz)	Typical Coupling* (dB)
742.5	26.0
878.0	26.0
1962.5	26.0
2145.0	26.0
2355.0	26.0

*The typical coupling value for the supported bands is -26 dB; however, a delta of +/- 3 dB can be expected. As such, the actual coupling value for each unit (measured for the DL center frequency of supported bands) is specified on a label on the unit. Note that the test port is bi-directional, so that a UL signal can also be injected and measured with a -26 dB loss.

Environmental Specifications

Operating Temperature	-40° to +65°C (-40° to 149°F)
Storage Temperature	-30° to 85°C (-22° to 185°F)

Standards and Approvals

Laser Safety	FDA/CE 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50 and IEC 60825-1
EMC/Radio	FCC 47 CFR Part 15, 22, 24, 27
Safety	UL 60950 IEC 60825-1:2007 IEC 60825-2:2010 CAN/CSA-C22.2 No. 60950-1-03
NEBS	GR-63, GR-1089, GR-487 (with outdoor enclosure)

Optical Specifications

Optical Output Power	< 9 dBm
Maximum Optical Budget	7 dB (5 dB over any temperature and optical variations)
Back Reflectance	-60 dB
Optical Connector	LC APC single-mode
Fiber Type	Corning® SMF-28® fiber or compatible
Wavelength	1310 ± 10 nm (at 25°C)

Physical Specifications

MRU Hosting Capabilities	<ul style="list-style-type: none"> • Five service-specific power amplifier modules (PAMs) • One optical module (OPTM) • One fan module (FAM) • One AC or DC (model dependent) power supply module (PSM) 	
Interfaces	<ul style="list-style-type: none"> • One 4.3-10 type duplexed RF antenna port • One LC APC port for fiber optic connection • One QMA coupling “Test Port” (used for UL and DL measurements during system operation) • One 4.3-10 type RF port for 2.5 GHz external RF source • One RJ45 MGMT (local) connection • One two-hole, standard barrel grounding lug; for use with stranded copper wire conductors; 10-14 AWG; holes – 1/4 in • “DC In” connectors (model dependent): <ul style="list-style-type: none"> • One “DC In” 2-pin “Class 1” terminal block • Two “DC In” 8-pin “Class 2” terminal block connectors: one pair for each PAM (total of five pairs) and one pair for the FAM and OPTM; one RSV pair • One QMA input connector for EXP UL • One QMA output connector for EXP DL • One DB9 female external alarm connector for external dry contact alarm connections 	
Power	<ul style="list-style-type: none"> • Power Consumption: DC version: 330 W (maximum) AC version: 360 W (maximum) • AC Power Input: 100-240 VAC/50-60 Hz • Maximum AC Current Consumption: 5 A • DC Power Input: <ul style="list-style-type: none"> • DC class 1: 48 VDC (40-60 VDC) 9 A maximum • DC class 2: 24/48 VDC (20-60 VDC) • Power amplifier consumption per pair: 50 W • Maximum power consumption: 330 W • Maximum current consumption: 1.75 A per pair • Maximum current draw per pair: 64 W 	
Management	Managed via the headend control module (HCM v1.6)	
Physical Characteristics	Mounting:	19-in rack (6U rack height), Wall mount (separately ordered accessory kit)
	Dimensions (H x W x D):	10.5 x 17.5 x 15.75 in* (266.7 x 445 x 400 mm) <i>*without brackets</i>
	Weight:	Chassis without PAMs: 48 lbs (21.8 kg) Each PAM: 4.7 lbs (2.15 kg)

Appendix B: Ordering Information

MRU Assembly Configurations*

Part Number	Description
MRU-ASM-DC	MRU-DC Assembly with OPTIM, FAM, and DC PSM (PAMs required)
MRU-78171923-DC	MRU-DC Assembly with five PAM modules supporting LTE700, ESMR, CELL, AWS, PCS, and WCS
MRU-781719-DC	MRU-DC Assembly with four PAM modules supporting LTE700, ESMR, CELL, AWS, and PCS
MRU-7819-DC	MRU-DC Assembly with three PAM modules supporting LTE700, ESMR, CELL, and PCS
MRU-81719-DC	MRU-DC Assembly with three PAM modules supporting ESMR, CELL, AWS, and PCS
MRU-71719-DC	MRU-DC Assembly with three PAM modules supporting LTE700, AWS, and PCS
MRU-ASM-AC	MRU-AC Assembly with OPTIM, FAM, and AC PSM (PAMs required)
MRU-78171923-AC	MRU-AC Assembly with five PAM modules supporting LTE700, ESMR, CELL, AWS, PCS, and WCS
MRU-781719-AC	MRU-AC Assembly with four PAM modules supporting LTE700, ESMR, CELL, AWS, and PCS
MRU-7819-AC	MRU-AC Assembly with three PAM modules supporting LTE700, ESMR, CELL, and PCS
MRU-81719-AC	MRU-AC Assembly with three PAM modules supporting ESMR, CELL, AWS, and PCS
MRU-71719-AC	MRU-AC Assembly with three PAM modules supporting LTE700, AWS, and PCS

Table 7-1. Part Numbers for MRU Assemblies Configurations

*Refer to Table 7-2 for part numbers for MRU assemblies which have been upgraded for future AWS1/3 support.

MRU Assembly Configurations Upgraded for Future AWS1/3 Support

Part Number	Description
MRU-E-78171923-DC	MRU-DC-AWSe Supported Assembly with five PAM modules supporting: LTE700, ESMR, CELL, PCS, AWS1, and WCS
MRU-E-781719-DC	MRU-DC-AWSe Supported Assembly with four PAM modules supporting: LTE700, ESMR, CELL, PCS, and AWS1
MRU-E-81719-DC	MRU-DC-AWSe Supported Assembly with three PAM modules supporting: ESMR, CELL, AWS1, and PCS
MRU-E-71719-DC	MRU-DC-AWSe Supported Assembly with three PAM modules supporting: LTE700, AWS1, and PCS
MRU-E-78171923-AC	MRU-AC-AWSe Supported Assembly with five PAM modules supporting: LTE700, ESMR, CELL, PCS, AWS1 and WCS
MRU-E-781719-AC	MRU-AC-AWSe Supported Assembly with four PAM modules supporting: LTE700, ESMR, CELL, PCS, and AWS1
MRU-E-81719-AC	MRU-AC-AWSe Supported Assembly with three PAM modules supporting: ESMR, CELL, AWS1, and PCS
MRU-E-71719-AC	MRU-AC-AWSe Supported Assembly with three PAM modules supporting: LTE700, AWS1, and PCS
MRU-E-ASM-AC-B	MRU-AC-AWSe Supported Assembly with OPTIM, FAM, and AC PSM modules
MRU-E-ASM-DC-B	MRU-DC-AWSe Supported Assembly with OPTIM, FAM, and DC PSM modules

Table 7-2. Part Numbers for MRU Assembly Configurations Upgraded for Future AWS1/3 Support

MRU Stand-Alone Modules

Note: Stand-alone modules can be ordered for upgrade or maintenance purposes.

Part Number	Description
MRU-OPTM-P	Mid-Power Remote Unit Optical Module Support IF and listening mode,
MRU-PAM-17	Mid-Power Remote Unit Power Amplifier Module supporting AWS 1700 MHz
MRU-PAM-8	Mid-Power Remote Unit Amplifier Module supporting ESMR800 and CELL 850
MRU-PAM-7	Mid-Power Remote Unit Power Amplifier Module supporting LTE 700 MHz
MRU-PAM-19	Mid-Power Remote Unit Power Amplifier Module supporting PCS 1900 MHz
MRU-PAM-23	Mid-Power Remote Unit Power Amplifier Module supporting PCS 2300 MHz
MRU-PSM-AC	Mid-Power Remote Unit AC Power Supply Module
MRU-PSM-DC	Mid-Power Remote Unit DC Power Supply Module
MRU-FAM	Mid-Power Remote Unit Modular Fan Module

Table 7-3. Part Numbers for MRU Stand-alone Modules

Accessories

Part Number	Description
BR-MRU-W	Mid-Power Remote Unit Wall Mounting Bracket (vertical installation)
AK-MRU-DCA-CBL	Mid-Power Remote Unit Dry Contact Cable Assembly (optional)

Table 7-4. Part Numbers for MRU Accessories

Cable Assemblies

<input type="text" value="H"/>	<input type="text" value="R"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text" value="8"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text" value="F"/>	-	<input type="text"/>	<input type="text"/>
		1	2		3		4	5	6	7		8	9					10	11

|1

Select end one connector.

00 = None

18 = LC APC duplex

66 = SC APC duplex

|4

Select cu conductor count.

0 = No conductors

2 = 2 conductors

4 = 4 conductors

6 = 6 conductors

|7

Select cable type.

U = Fiber and copper conductors

G = Fiber only

|2

Select end two connector.

08 = LC APC duplex

66 = SC APC duplex

|5

Select cu connectors.

C = With connectors

N = No connectors

|8

Select armored or non-armored.

20 = Non-armored

A3 = Armored indoor plenum

|3

Select cu wire gauge.

F = 12 AWG

G = 14 AWG

H = 16 AWG

|6

Select fiber count.

04 = 4 fibers

06 = 6 fibers

24 = 24 fibers (see Note 1)

48 = 48 fibers (see Note 1)

72 = 72 fibers (see Note 1)

96 = 96 fibers (see Note 1)

E4 = 144 fibers

|9

Select cable length.

010-999 ft (see Note 2)

|10

Select pulling grip.

P = One-sided pulling grip

N = No pulling grip

|11

Select kit.

K = Two strain-relief
trunk holders (see Note 3)

N = None

Note 1: Fiber-only trunk cables (no conductive pairs); MTP® connector is standard – for other options, please contact Customer Care.

Note 2: Cable lengths:

- Preconnectorized cable can only be ordered in 10-ft increments.

- Non-connectorized bulk cabling can only be ordered in 50-ft increments.

Note 3: Available for 24-144 fiber cables only.

CORNING

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P/N 709C017501

EXHIBIT D

Corning ONE™ Wireless Platform MRU



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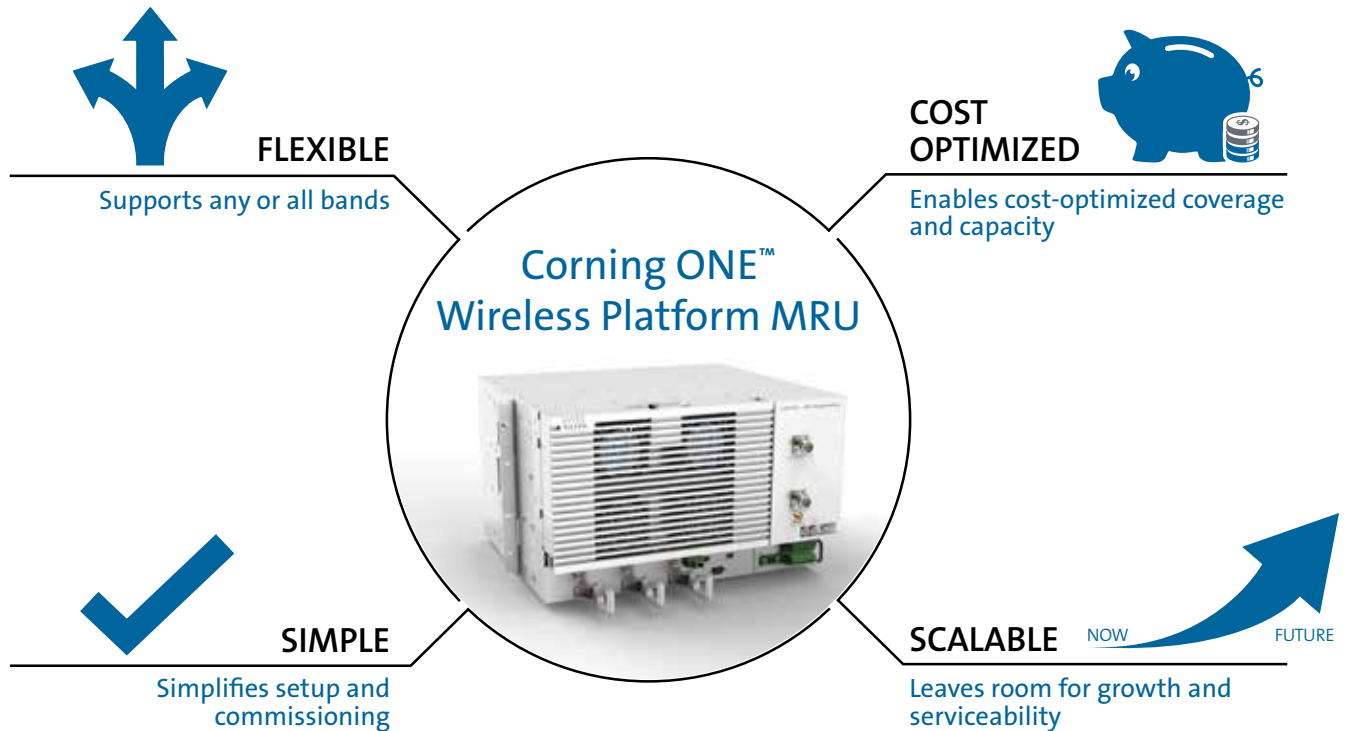
Corning ONE™ Wireless Platform MRU

The mid-power remote unit (MRU) is a fiber-fed, 33 dBm remote unit designed to complement the Corning ONE wireless platform, adding higher power capabilities for both indoor and outdoor deployments.

- **FLEXIBLE: Neutral host support**
Supports up to seven bands: 700, 800, 850, 1900, 2100, 2300, 2500.
- **COST OPTIMIZED: Enables cost-optimized coverage and capacity**
Combine the MRU with the low-power RAU for cost-optimized coverage and capacity in any type of venue, both indoors and out. Connect multiple buildings or sites to a headend located up to 20 km away.
- **SIMPLE: Simplifies setup and commissioning**
Autodiscovery of all network components and built-in system testing significantly reduce commissioning time.
- **SCALABLE: Leaves room for growth and serviceability**
Slide in amplifiers for new bands, add MIMO for more capacity, and resectorize as needed. Upgrades can be done while system is live, as they are non-service affecting.

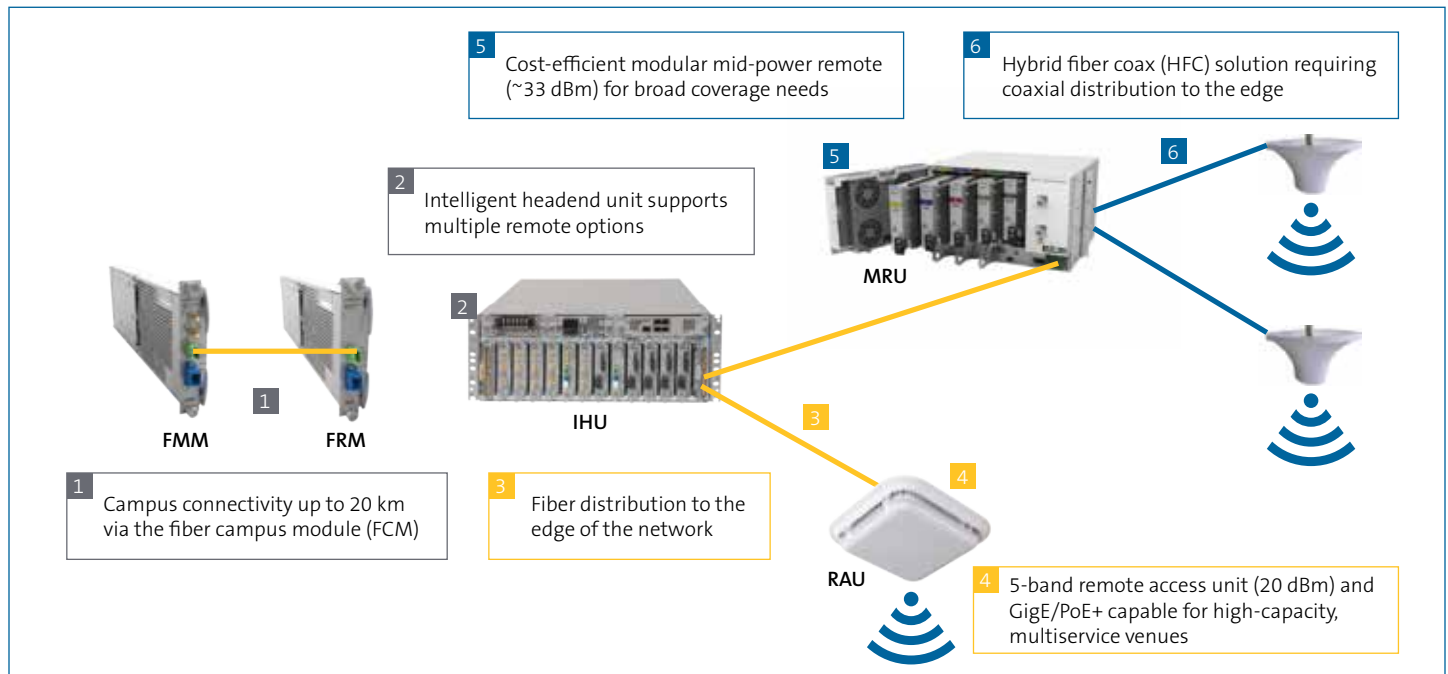
MRU Highlights:

- **Modular** – Add bands as needed
- **Smaller form factor** – 6U remote supporting seven bands
- **Common headend** – Combine low- and medium-power remotes for cost-optimized coverage and capacity
- **NEBS certified** – Can be installed indoor in AC/non-AC environments, and in outdoor environments
- **Low PIM connectors** – Greatly reduce intermodulation and increase performance
- **Test port** – Monitoring and diagnostics without impacting service



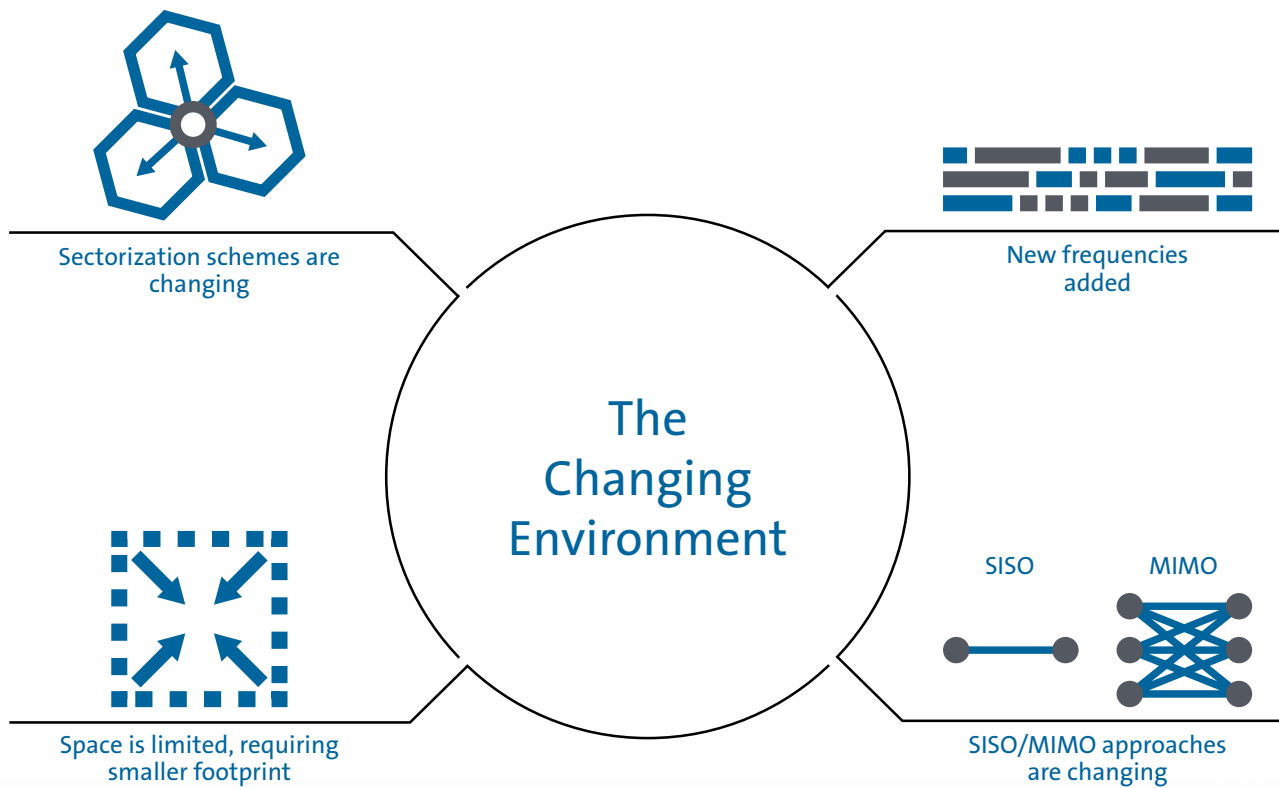
Indoor, Outdoor. Open or Dense Environments

When dealing with sites with various RSSI requirements, dense and open topologies, or sites requiring both indoor and outdoor coverage, combine the MRU with the low-power RAU for efficient, cost-optimized coverage. The MRU and the low-power RAU connect to the same Corning ONE wireless platform headend.



DAS Requirements Continue to Change

The needs and requirements for a typical DAS are constantly shifting: sectorization schemes tend to change, new frequencies on existing bands are being utilized, approaches for SISO/MIMO are modified, and new bands are being deployed. When evaluating a DAS, consider not only current requirements but also how easily a solution can adapt to future needs.



Simplified Setup and Management

Corning ONE wireless platform software provides a differentiated DAS management solution by focusing on providing enhanced system performances and serviceability improvements while continuing to address your requirements. The Corning ONE wireless platform comes equipped with multiple advanced features that simplify set up, commissioning, and management of the platform:

- Autodiscovery of all network components
- Built-in system test for quicker troubleshooting
- Support for SNMPv3 enables read and write parameters



Unlock the box – pay for the bands you want today,
plug in the ones you'll need tomorrow.

For more information, visit www.corning.com/MRU
or email CMAContactUs@corning.com



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